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Submitted in partial fulfillment of the
requirements for the degree of

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## ABSTRACT

The spectral method of sea and swell wave forecasting yields more meaningful results than do other forecasting methods. To shorten the time required to make such a forecast the authors used high-speed computer methods and the Pierson-Neumann-James spectra to make spectral forecasts and display the results in graphic form for several synoptic weather models and a wide range of wind and fetch speeds. Forecasts were completed for a stationary fetch model, a fetch moving to leeward and a fetch moving to windward.

Computations were made with the assumptions that a rectangular generating area could be delineated; that a spatially-uniform mean wind existed; that this wind did not increase or decrease until the time of forecast; and finally that if the fetch were moving, its movement was steady.

The following parameter limits were established:

a. wind speeds, 15 to 55 knots;

b. speed of the generating area, 15 knots to and including the wind speed;

c. forecast times, 6 to 72 hours.

Results of the forecasts are plotted on approximately 250 graphs which show the geographic distribution of spectral sea or swell components relative to the fetch at forecast times.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

## LIST OF TABLES

## 1. Introduction

It is universally understood that a need exists for a quick, yet accurate method for forecasting the wave conditions on the surface of the oceans of our planet. However it must be strongly emphasized that such a method should be spectral. It is important that the range of periods as well as heights of the waves be forecast. Some examples of where knowledge of wave periods is important are as follows:

(1) the emergency ditching of aircraft at sea,

(2) seaplane and aircraft carrier flight operations,

(3) refraction and shoaling of waves as they approach a shoreline,

(4) submarine surfacing and submergence.

This need for rapid spectral wave forecasting prompted the authors of this paper to perform the study and work herein discussed.

## 2. Background

Generally two catagories of forecast methods are available, a spectral method and a non-spectral method. The spectral forecast has the advantage of determining the range of periods with important energy but is a very tedious, time-consuming process. Furthermore, the technique requires that the forecaster be trained quite extensively. The non-spectral method has an advantage in that a forecast can be made rather rapidly and by a person with minimal training. However, it does not tell the user of the forecast the range of periods in which the wave energy lies.

Therefore, in order to permit accurate and more meaningful spectral forecasts by relatively untrained persons, high-speed computer methods were used to make spectral forecasts for as many synoptic weather models as time would permit and to display the results of the computer output in graphic form.

## 3. Basis of the Forecast Method

The Pierson-Neumann-James forecast method as outlined in H. O. Pub. No. 603 [3] was chosen as the basis for the wave forecasts. In order to avoid repeating a great volume of theory and methods, it will be assumed that the reader has a working knowledge of this publication. It is recognized that Pierson and Moskowitz [1 and 2] are developing new spectra which will improve upon the PNJ spectra now in widespread use. Therefore, the computer programs were written in such a manner as to allow utilization of these new spectra or others as they are published.

In making a forecast of sea and swell conditions, one must know at what location within the generating area and how long after the wind began to blow that waves of a given period are first formed. This information is gleaned from the Co-Cumulative Spectra. Then one must know the velocity with which the waves are propagated. Each spectral component moves at its respective group velocity, the direction being accounted for by an angular spreading function. When these characteristics have been determined, the distribution of wave periods over any geographical area can be shown graphically.

For each wind speed and fetch description considered, this distribution is shown for various times since the wind started blowing.

## 4. Synoptic Models Completed

To date, three models have been completed:

(1) a stationary fetch model which may be associated with a stationary cyclone, trough or ridge;

(2) a model with a fetch moving to leeward, as associated with the southern quadrant of a cyclone moving eastward;

(3) a model with a fetch moving to windward as associated with the northern quadrant of a cyclone moving eastward.

In the following sections the variables and equations associated with each model are discussed.

A discussion of the computer programming and procedures is found in Appendix A.

## 5. Stationary Fetch Model

### 5.1 FOPRIME

With this case a description of wave conditions within the generating area (SEA) must be given. In order to generate waves of a given period, the wind must blow over a minimum length of fetch for a sufficient time. This minimum distance, measured from the windward edge of the fetch, is given the name FOPRIME. The values for each period are determined from the CCS,

$$FOPRIME = F_o'(V,t_d) \tag{1}$$

where V is the wind velocity and $t_d$ is the duration time. Graphs for specified velocities and various times of observation show plots of the highest period present versus FOPRIME. These graphs are also called FOPRIME. The use of these and all other graphs is explained in Section 10.

### 5.2 SWELL

A description of the waves emanating from the generating area (SWELL) in the general direction of the wind also must be given. As soon as a spectral component with period $T_i$ is formed, it moves with a group velocity,

$$V_i = 1.515\ T_i(V,t_d) \tag{2}$$

where $T_i$, the period of the longest wave, is a function of wind velocity and duration. Assuming that all swell waves are propagated from the leeward edge of the fetch, their maximum distance from this edge at some observation time $t_{ob}$ is:

$$SWELL = (t_{ob} - t_d)V_i. \tag{3}$$

Graphs of spectral component versus SWELL for various observation times are also called SWELL.

## 6. Moving (leeward) Fetch Model

### 6.1 FOPRIME

For this synoptic model the description of the SEA conditions within the windward and leeward portions of the fetch must be given. Since the fetch is moving, it is assumed that the windward portion of the fetch is completely filled in with waves that have group velocities less than the fetch velocity. FOPRIME for each spectral component with group velocity greater than the fetch velocity is obtained from the CCS. The graphs showing the distribution of spectral components versus FOPRIME are called FOPRIME.

### 6.2 SUMDEL

Due to the movement of the fetch into an area where it is assumed calm seas exist, the effective duration of the wind blowing over the leeward portion of the fetch is less than for a stationary fetch. Therefore, the distance behind the leading edge of the fetch that a spectral component of period, $T_i$, can first be formed during an increment of duration time $\Delta t_i$ is

$$\Delta D_i = (V_f - 1.515\ T_i)\ \Delta t_i \tag{4}$$

where $V_f$ is the fetch velocity. Each spectral component requires a specific generation time; a summation of the duration increments $\Delta t_i$ determines this generation time, $t_d = \sum_{i=1}^{N} \Delta t_i$ . The summation of $\Delta D$'s determines the total lag of that component behind the leading edge of the fetch; this distance is called SUMDEL.

$$\text{SUMDEL} = \sum_{i=1}^{N} \Delta D_i . \tag{5}$$

If a spectral component generated at a particular time $t_d$ has a group velocity greater than the fetch velocity, then at time $t_{ob}$ this component has advanced relative to the leading edge of the fetch an amount,

$$\text{DIST} - (t_{ob} - t_d)\ V_f,$$

where DIST is the travel distance of the component since it was generated and $(t_{ob}-t_d)\ V_f$ is the distance the fetch advances during this same period of time.

$$DIST = (t_{ob}-t_d)\ V_i \tag{6}$$

Hence SUMDEL is modified by this relative travel of the high-speed spectral component. The resulting distance that a specific spectral component lags behind the leading edge of the moving fetch at $t_{ob}$ is called SWEDEL.

$$SWEDEL = SUMDEL - DIST + (t_{ob}-t_d)\ V_f. \tag{7}$$

6.3 SWELL

The distribution of the swell to leeward of the fetch is similar to that in the stationary fetch model, but since the fetch is moving it becomes necessary to consider the distance traveled by the leading edge since the generation of a specific spectral component, $(t_{ob}-t_d)\ V_f$, and SUMDEL, the distance behind the leading edge that a specific component is formed. Thus, in this case,

$$SWELL = (t_{ob}-t_d)\ V_i - (t_{ob}-t_d)\ V_f - SUMDEL. \tag{8}$$

Graphs showing the range of periods of the spectral components versus SWELL for various observation times are called SWELL.

6.4 LAG

As the fetch moves to leeward at a specific velocity, spectral components with group velocities lower than the fetch velocity fall out of the windward portion of the fetch, assuming as before that the windward part of the fetch is completely filled in by these spectral components. The distance that a wave component with period $T_i$ lags behind the trailing edge of the fetch at $t_{ob}$ is termed LAG, where

$$LAG = (t_{ob}-t_d)\ V_f - (t_{ob}-t_d)\ V_i, \tag{9}$$

or by rearranging terms

$$LAG = (t_{ob} - t_d)\,(V_f - V_i)\ . \tag{10}$$

Graphs showing the distribution of spectral components versus LAG are called LAG.

## 7. Moving (windward) Fetch Model

For this situation only two of the areas previously mentioned need describing, the area within the fetch and the area behind the trailing edge where swell is found.

### 7.1 SUMDEL

The distance behind the leading edge of the fetch that a specific spectral component is first formed is called SUMDEL as defined by (5). Since the fetch movement and wind direction are opposite, (4) is modified to

$$\Delta D_i = (V_f + 1.515\ T_i)\ \Delta t_i. \tag{11}$$

The graphs describing the generating area in this case are called SUMDEL.

### 7.2 LAG

Immediately upon generation, waves of a given spectral component move out of the generating area. Their distance behind the trailing edge is called LAG. Because of the opposite directions of movement of fetch and wind, equation (10) becomes

$$LAG = (t_{ob} - t_d)(V_f + V_i). \tag{12}$$

The graphs depicting the location of spectral components behind the fetch at a specific observation time are called SWELL.

8. Definitions Used in the Forecast Method

To make clear the notations used in subsequent sections, the following terms are defined. Most terms are the same as those used in [3]. However, some of the terms are unique to this paper.

Fetch - That limited or bounded area of the ocean where it is assumed a mean steady wind is blowing and generating waves. The area is also assumed to be rectangular with one axis along the wind path. Also referred to as a generating area.

Sea - Those waves found within the generating area.

Swell - Those waves which have moved out of a generating area.

$R_o$ - The distance from the center of the leeward edge of a generating area to the point P at which a forecast will be made.

$R_s$

$L_o$ - The distance from the center of the windward edge of a moving (leeward) fetch to P, measured in a direction opposite to fetch motion.

$\bar{T}$

$T_U$ - The highest wave period in either a sea or swell. $T_U$ is a function of wind speed and duration.

$T_{FU}$ - The highest wave period in either a sea or swell where a relatively short fetch limits the growth of waves. Refer to section 13.1d.

$T_L$ - The lowest period in either a sea or swell.

$E_U$ - The energy in that part of the spectrum between the periods zero and $T_U$.

$E_L$ - The energy in that part of the spectrum between the periods zero and $T_L$.

$\Delta E$ - The energy associated with that portion of the wave spectrum with periods from $T_L$ to $T_U$. $\Delta E = E_U - E_L$.

$\theta_3$, $\theta_4$ - The angles between the direction of the mean wind and the lines drawn from P to the center of each side of the fetch.

$S_\theta$ - The angular spreading factor, determined by $\theta_3$ and $\theta_4$ from the Angular Spreading Factor Table, explained in Section 11.

$\Delta E_\theta$ - The total increment of energy arriving at P at a specific time. This energy is a function of wind speed, fetch speed, distance from the fetch and the relative direction of P from the fetch. $\Delta E_\theta = \Delta E(S_\theta) = (E_U - E_L)(S_\theta)$

$t_{ob}$ - The time of the forecast, measured from the time the wind began to blow (e. g. if the wind begins at 010000Z and a forecast at P is to be made for 020600Z then $t_{ob}$ is 30 hours). Also referred to as observation time.

$V$ - Mean wind speed in knots.

$V_f$ - Mean fetch speed in knots.

## 9. Parameter Limits

The range of wind velocities considered for the computer computations was from 15 to 55 knots. Below 15 knots, the wave energy is considered insignificant. The upper limit of 55 knots is controlled by the fact that the PNJ spectra are given only up to 56 knots. Since facsimile weather maps show wind speeds in increments of five knots, this increment value was used for the computations.

The range of fetch velocities used was from 15 knots up to the existing wind velocity. It was considered unlikely that a delineated generating area would move faster than the wind velocity within it. For fetch velocities less than 15 knots, it was considered that the stationary fetch graphs could be used, assuming some mean location of the fetch.

Graphs to forecast sea and swell conditions were drawn for observation times from 6 to 72 hours. The upper limit was arbitrarily set by the authors. The observation time was incremented by six hours for convenience. Any other times can be found by interpolation.

For the moving-fetch models, a fetch-length limitation of 1600 nautical miles was established for reasonable graph scaling. This limitation seems reasonable since it is doubtful that a uniform wind field larger than this would be found. This fetch limitation is especially noticeable in limiting the formation of low-frequency waves in the Moving (windward) Fetch Model.

## 10. Use of Graphs

Each of the graphs discussed has 12 separate or superimposed curves showing the range of wave periods at geographic locations for observation times from $t_{ob}$ = 6 hours to $t_{ob}$ = 72 hours at six-hour intervals. Fig. 1 shows a time series of graphs approximating a situation where a generating area with a mean wind velocity of 35 knots (V = 35) moves across the ocean with a fetch velocity of 20 knots ($V_f$ = 20). The final graph in each column is the composite picture where curves for all times are superimposed. The shaded areas in each case show the range of periods present at all locations. All distances measured on the graphs are relative to the windward or leeward edge of the fetch.

To make forecasts for times other than those of the observation time curves, the forecaster may interpolate between curves.

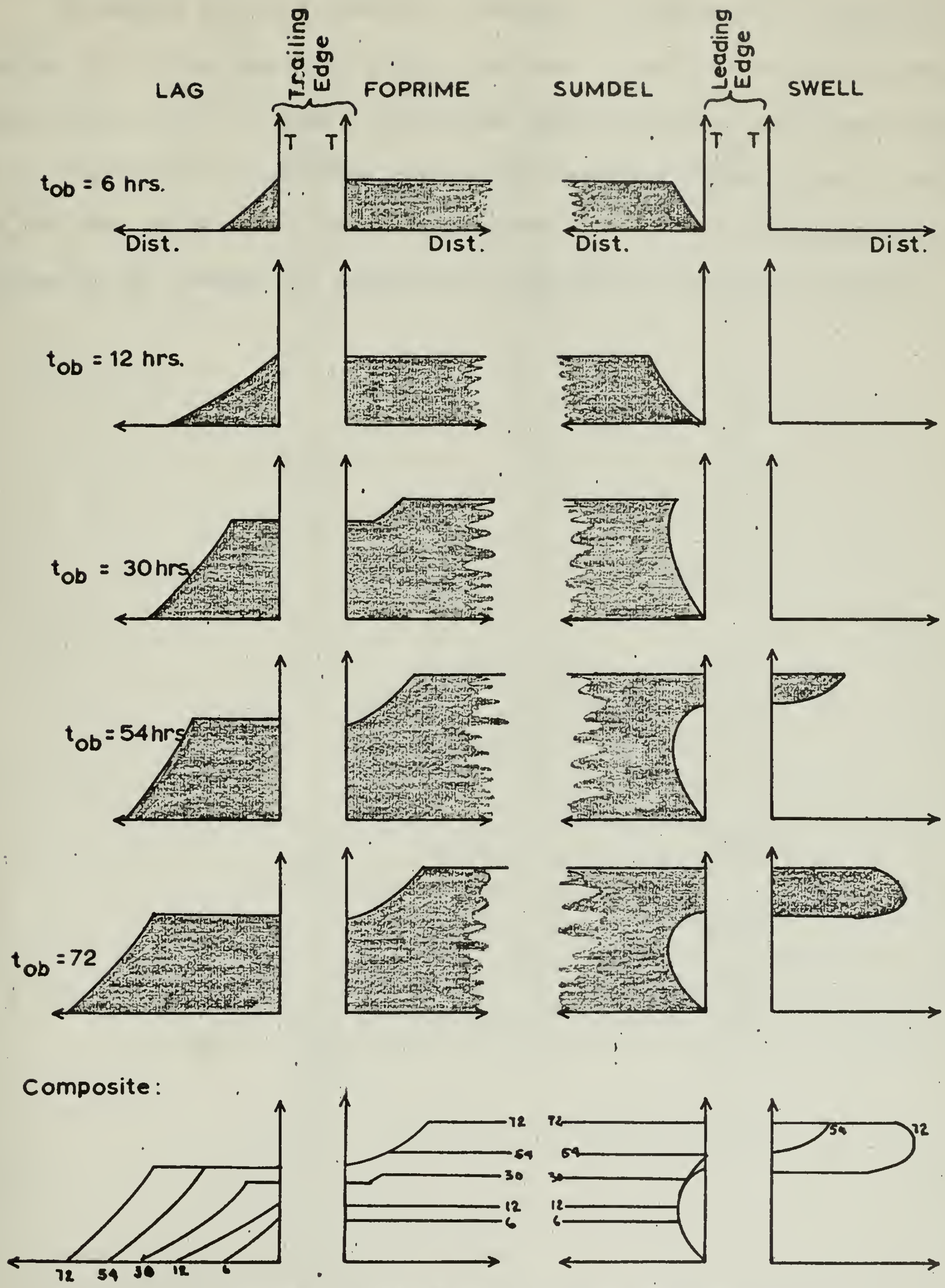



Figure 1. Time Series of Graphs Showing Distribution of Spectral Wave Components Relative to a Moving (leeward) Fetch.

## 11. Use of the Angular Spreading Table

The angles $\theta_3$ and $\theta_4$ defined in Section 8 determine the reduction of energy due to the angular spreading the waves undergo after leaving the generating area. The angular spreading factor nomograph in [3] was used to formulate Table 1, showing the angular spreading factor $S_\theta$ as a function of the two angles in ten-degree increments. It is felt that measuring these angles to the nearest ten degrees gives sufficiently accurate results.

| $\theta_4 \backslash \theta_3$ | -80° | -70° | -60° | -50° | -40° | -30° | -20° | -10° | 0 | +10° | +20° | +30° | +40° | +50° | +60° | +70° | +80° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -80° | - | .01 | .03 | .07 | .12 | .20 | .30 | .40 | .50 | .60 | .70 | .80 | .88 | .93 | .97 | .99 | 1.0 |
| -70° | .01 | - | .02 | .06 | .11 | .19 | .29 | .39 | .49 | .59 | .69 | .79 | .87 | .92 | .96 | .98 | .99 |
| -60° | .03 | .02 | - | .04 | .09 | .17 | .27 | .37 | .47 | .57 | .67 | .77 | .85 | .90 | .94 | .96 | .97 |
| -50° | .07 | .06 | .04 | - | .05 | .13 | .23 | .33 | .43 | .53 | .63 | .73 | .81 | .86 | .90 | .92 | .93 |
| -40° | .12 | .11 | .09 | .05 | - | .08 | .18 | .28 | .38 | .48 | .58 | .68 | .76 | .81 | .85 | .87 | .88 |
| -30° | .20 | .19 | .17 | .13 | .08 | - | .10 | .20 | .30 | .40 | .50 | .60 | .68 | .73 | .77 | .79 | .80 |
| -20° | .30 | .29 | .27 | .23 | .18 | .10 | - | .10 | .20 | .30 | .40 | .50 | .58 | .63 | .67 | .69 | .70 |
| -10° | .40 | .39 | .37 | .33 | .28 | .20 | .10 | - | .10 | .20 | .30 | .40 | .48 | .53 | .57 | .59 | .60 |
| 0 | .50 | .49 | .47 | .43 | .38 | .30 | .20 | .10 | - | .10 | .20 | .30 | .38 | .43 | .47 | .49 | .50 |
| +10° | .60 | .59 | .57 | .53 | .48 | .40 | .30 | .20 | .10 | - | .10 | .20 | .28 | .33 | .37 | .39 | .40 |
| +20° | .70 | .69 | .67 | .63 | .58 | .50 | .40 | .30 | .20 | .10 | - | .10 | .18 | .23 | .27 | .29 | .30 |
| +30° | .80 | .79 | .77 | .73 | .68 | .60 | .50 | .40 | .30 | .20 | .10 | - | .08 | .13 | .17 | .19 | .20 |
| +40° | .88 | .87 | .85 | .81 | .76 | .68 | .58 | .48 | .38 | .28 | .18 | .08 | - | .05 | .09 | .11 | .12 |
| +50° | .93 | .92 | .90 | .86 | .81 | .73 | .63 | .53 | .43 | .33 | .23 | .13 | .05 | - | .04 | .06 | .07 |
| +60° | .97 | .96 | .94 | .90 | .85 | .77 | .67 | .57 | .47 | .37 | .27 | .17 | .09 | .04 | - | .02 | .03 |
| +70° | .99 | .98 | .96 | .92 | .87 | .79 | .69 | .59 | .49 | .39 | .29 | .19 | .11 | .06 | .02 | - | .01 |
| +80° | 1.0 | .99 | .97 | .93 | .88 | .80 | .70 | .60 | .50 | .40 | .30 | .20 | .12 | .07 | .03 | .01 | - |

TABLE 1. ANGULAR SPREADING FACTOR

12. Use of the Energy Table

For a rapid forecast, measuring the range of wave periods to the nearest whole second at any given location seems sufficiently accurate. Hence the simplified Energy Table (Table 2) gives the energy associated with a spectrum of waves with periods from zero to T, listed on the left vertical edge of the table. Enter this table with V, and $T_U$ or $T_L$ to determine $E_U$ or $E_L$ respectively. For more accuracy, the period to the nearest tenth may be read from the graphs and the energy value from Table 2 interpolated. These extracted values have units, $feet^2$.

| T (SEC) \ V (Kts) | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 |
|---|---|---|---|---|---|---|---|---|---|
| 4 | .4 | .7 | .7 | 1.0 | 1.5 | 2.5 | 3.1 | 3.6 | 4.3 |
| 5 | .7 | 1.6 | 2.2 | 2.9 | 3.5 | 4.2 | 5.0 | 5.6 | 5.9 |
| 6 | 1.1 | 3.0 | 4.4 | 5.1 | 6.0 | 7.8 | 8.8 | 10.0 | 11.0 |
| 7 | 1.4 | 3.9 | 6.1 | 8.3 | 9.5 | 12.0 | 15.0 | 17.5 | 20.0 |
| 8 | 1.7 | 5.0 | 9.3 | 14.5 | 17.5 | 22.0 | 24.0 | 28.0 | 32.0 |
| 9 | 1.9 | 5.8 | 12.5 | 21.0 | 26.5 | 32.0 | 37.0 | 43.0 | 47.0 |
| 10 | | 6.2 | 16.0 | 29.0 | 40.0 | 50.0 | 65.0 | 70.0 | 74.0 |
| 11 | | 7.0 | 17.5 | 34.5 | 50.0 | 68.0 | 86.0 | 95.0 | 100 |
| 12 | | 7.7 | 20. | 40. | 64. | 90. | 107. | 130. | 145. |
| 13 | | | 22. | 45. | 75. | 110. | 132. | 170. | 195. |
| 14 | | | 24. | 47. | 86. | 130. | 168. | 220. | 255. |
| 15 | | | | 50. | 96. | 160. | 210. | 270. | 315. |
| 16 | | | | 55. | 106. | 180. | 255. | 325. | 400. |
| 17 | | | | 59. | 112. | 190. | 285. | 390. | 450. |
| 18 | | | | | 123. | 205. | 320. | 450. | 525. |
| 19 | | | | | 128. | 220. | 350. | 500. | 620. |
| 20 | | | | | | 230. | 375. | 530. | 700. |
| 21 | | | | | | 243. | 410. | 600. | 770. |
| 22 | | | | | | 247. | 420. | 630. | 820. |
| 23 | | | | | | | 430. | 660. | 860. |
| 24 | | | | | | | 450. | 700. | 900. |
| 25 | | | | | | | | 715. | |
| 26 | | | | | | | | 730. | |

TABLE 2. ENERGY TABLE

## 13. Forecasting Procedures

The following is a concise, step-by-step procedure to be followed in making a forecast.

### 13.1 Preliminary steps

a. Draw the boundaries of the generating area on a synoptic weather chart; determine the mean wind, V, within the area and if the fetch is moving determine a mean fetch speed, $V_f$.

b. Locate the point of interest, P, where the forecast is to be made.

c. Determine into which of the synoptic models the forecast falls:

1. Stationary Fetch Model (Section 13.2)

2. Moving (leeward) Fetch Model (Section 13.3)

3. Moving (windward) Fetch Model (Section 13.4)

### 13.2 Stationary Fetch Model

A sea or swell forecast is made for P depending on the location relative to the fetch as shown in Fig. 2.

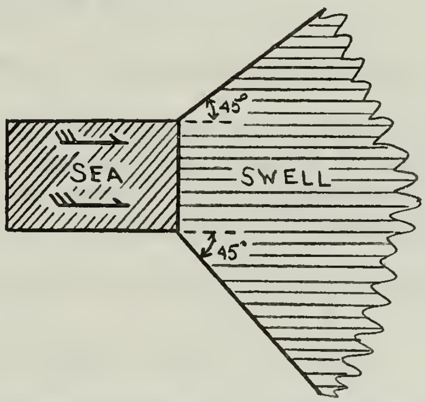



Figure 2. Sea and Swell Areas Associated with a Stationary Fetch

a. Sea Forecast

1. Measure the distance from P to the windward edge of the fetch.

2. Enter the FOPRIME graph for the appropriate windspeed with this distance and $t_{ob}$ to obtain $T_U$.

3. Assume $T_L$ is zero; therefore, $E_L$ is zero.

4. From Table 2 determine $E_U$, a function of $T_U$ and V.

5. Assume that within the generating area the angular spreading factor $S_\theta$ is unity; therefore, $\Delta E_\theta$ equals $E_U$.

6. For characteristic wave height computation, refer to the formulae in Table 3.

b. Swell Forecast

(If P lies outside the sector outlined in Fig. 2, swell will be considered insignificant.) [See Note]

1. Determine as outlined below if the length of the fetch will limit the growth of waves (e.g., a 30-knot wind with a duration of 24 hours can produce waves with periods up to 16.7 seconds if the fetch length is at least 280 nautical miles. If the fetch length is only 200 NM, the highest period of wave which can be generated is 11.7 seconds). Enter the FOPRIME graph for the given V, $V_f$ and $t_{ob}$ with fetch length to determine the highest period of waves generated. If this period is less than the highest period on that $t_{ob}$ curve, then it is called $T_{FU}$ and replaces $T_U$ in the remainder of the swell forecast. (See Example Forecast No. 1.)

2. Measure $R_o$.

3. Enter SWELL graph for appropriate V and $t_{ob}$ and obtain $T_U$ (or $T_{FU}$) and $T_L$.

4. From Table 2 determine $E_U$ and $E_L$.

5. Draw lines from P to the centers of the sides of the generating area and measure angles $\theta_3$ and $\theta_4$ as shown in Fig. 6. Angles are negative if measured clockwise from the wind direction, and positive if measured counterclockwise.

6. Enter Table 1 with $\theta_3$ and $\theta_4$ and determine $S_\theta$.

7. Calculate $\Delta E_\theta = (E_U - E_L)(S_\theta)$

8. Use formulae in Table 3 to determine wave heights.

13.3 Moving (leeward) Fetch Model

Fig. 3 is an aid in determining the type of waves to be forecast. Prior to any other steps the fetch must be tracked ahead to its location at the time of forecast, $t_{ob}$.

Note: When a long generating area exists, swell may emanate from the sides of the fetch. In such cases, the 45°-sectors shown on Fig. 2 may be moved toward the windward edge of the fetch an amount deemed necessary by the forecaster.

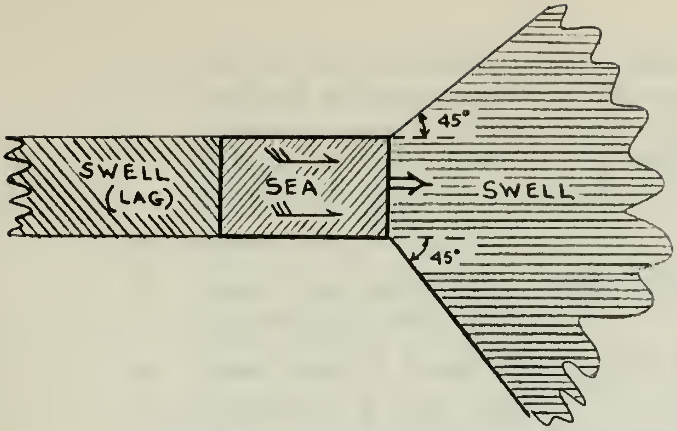



Figure 3. Sea and Swell Areas Associated with a Moving (leeward) Fetch.

a. Sea Forecast

(Since the graphs are drawn to cover a wide range of conditions, the highest period of sea waves may be determined from either the FOPRIME or SUMDEL graph. Generally, for slow fetch speeds $T_U$ will be determined from the FOPRIME graph and for high fetch speeds $T_U$ will be determined from the SUMDEL graph; therefore, both graphs should be investigated.)

1. Measure the distance from P to the trailing edge of the fetch.
2. Enter the appropriate FOPRIME graph with this distance and $t_{ob}$ to obtain $T_U$.
3. Measure the distance from P to the leading edge of the fetch.
4. Enter the appropriate SUMDEL graph with this distance and $t_{ob}$ to obtain $T_U$. If two separate bands of wave periods are in evidence, assume all periods between zero and $T_U$ are present.
5. Using the smaller of the two values of $T_U$ obtained in steps 2 and 4, enter Table 2 and obtain $E_U$.
6. Assume $T_L$ is zero; therefore, $E_L$ is zero.
7. Assume $S_\theta = 1$; therefore $\Delta E_\theta = E_U$.
8. Use the formulae in Table 3 to determine wave heights.

b. Swell Forecast for Area Leeward of the Fetch

(Swell is present ahead of the generating area only in the sector shown on Fig. 3 and only if the fetch is moving at speeds of 20 knots or less.)

1. As in the Stationary Fetch Model forecast (Section 13.2b), it must be determined if the fetch length limits the generation of waves. With fetch length enter the FOPRIME and SUMDEL graphs for the given V, $V_f$ and $t_{ob}$ to determine $T_{FU}$ from each graph and select the lower of these values.
2. Measure $R_o$.
3. Enter the appropriate SWELL graph with $R_o$ and $t_{ob}$ to obtain $T_U$ (or $T_{FU}$) and $T_L$.
4. From Table 2 determine $E_U$ and $E_L$.
5. Determine $\theta_3$, $\theta_4$ and $S_\theta$.
6. Calculate $\Delta E_\theta = (E_U - E_L)\ (S_\theta)$.
7. Use formulae in Table 3 to determine wave heights.

c. Swell Forecast for Area Windward of the Fetch

1. Measure $L_o$.
2. Enter the appropriate LAG graph with $L_o$ and $t_{ob}$ to obtain $T_U$.
3. Assume $T_L$ is zero; therefore, $E_L$ is zero.
4. From Table 2 determine $E_U$.
5. Since it is difficult to determine an angular spreading factor for swell waves traveling slower than the fetch, assume $S_\theta = 1.0$ and hence the swell heights are the maximum possible for this area. Hence, $\Delta E_\theta = E_U$.
6. Refer to Table 3 for height computations.

## 13.4 Moving (windward) Fetch Model

Fig. 4 describes the location of swell relative to the generating area. Prior to any forecasting steps the fetch must be tracked ahead to its location at $t_{ob}$.

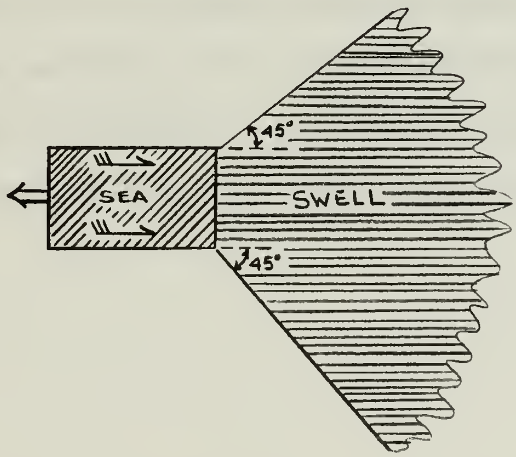



Figure 4. Sea and Swell Areas Associated with a Moving (windward) Fetch.

a. Sea Forecast

1. Measure the distance from P to the leading edge of the fetch.

2. Enter the appropriate SUMDEL graph with this distance and $t_{ob}$ to determine $T_U$.

3. From Table 2 determine $E_U$.

4. Assume $T_L$ is zero; therefore $E_L$ is zero.

5. Assume $S_\theta = 1.0$; therefore, $\Delta E_\theta = E_U$.

6. Refer to Table 3 for height computations.

b. Swell Forecast

1. Determine if the fetch length limits the growth of waves by entering the appropriate SUMDEL graph with fetch length and $t_{ob}$ as in Section 13.2b.

2. Measure $R_o$.

3. Enter the appropriate SWELL graph with $R_o$ and $t_{ob}$ to obtain $T_U$ (or $T_{FU}$) and $T_L$.

4. From Table 2 determine $E_U$ and $E_L$.

5. Measure $\theta_3$ and $\theta_4$ and obtain $S_\theta$ from Table 1.

6. Calculate $\Delta E_\theta = (E_U - E_L)(S_\theta)$.

7. Refer to Table 3 for height computations.

## 13.5 Multiple Storms

Should it appear that the forecast location might be under the influence of more than one storm, the increments of energy, $\Delta E_\theta$, at P from each storm should be calculated individually and then summed. Height characteristics are computed from this summed energy increment.

## 14. Wave Heights

The following formulae used most often are the same as those appearing in [3]; they have been modified only to agree with the symbols used in this paper. For determining range of heights, exceptionally high waves, and amplitude information, refer to [3], Chapter I.

Table 3. Wave Heights.

| | |
|---|---|
| Most frequent height . . . . . . . . . . . | $H_{freq} = 1.41\sqrt{\Delta E_\theta}$ |
| Average wave height. . . . . . . . . . . . | $H_{ave} = 1.77\sqrt{\Delta E_\theta}$ |
| Significant wave height (highest 1/3). . | $H_{1/3} = 2.83\sqrt{\Delta E_\theta}$ |
| Average height of highest 1/10 . . . . . | $H_{1/10} = 3.60\sqrt{\Delta E_\theta}$ |

15. Forecast Worksheet

In order to systematize the described processes, a worksheet (Fig. 5) was devised. The blanks provided are filled with information extracted from the graphs and tables of the system. It is recommended that any unit using the forecast method reproduce this worksheet. The completed worksheet may be kept on file to provide a permanent record.

## Sea and Swell Forecast Worksheet

Forecaster: ______ Location: ______(Lat.) ______(Long.) Time: ______Z $t_{ob}$: __ hrs. Approved: ______

V: ______ $V_f$: ______ Fetch Length: ______

### STATIONARY FETCH

SEA:

Dist. P to Wind. Edge: ______

$T_U$: ______, $E_U = \Delta E_\theta$: ______

$H_{1/3}$: ______

SWELL:

$R_o$: ______

$T_U$: ______, $E_U$: ______

$T_L$: ______, $E_L$: ______

$\theta_3$: ______, $\theta_4$: ______, $S_\theta$: ______

$\Delta E_\theta = (E_U - E_L)(S_\theta)$: ______

$H_{1/3}$: ______

### MOVING (LEEWARD) FETCH

SEA:

Dist. P $\begin{cases} \text{from Trailing Edge: ______} \\ \text{to Leading Edge: ______} \end{cases}$

$T_U$: ______, $E_U = \Delta E_\theta$: ______

$H_{1/3}$: ______

SWELL:

$R_o$: ______

$T_U$: ______, $E_U$: ______

$T_L$: ______, $E_L$: ______

$\theta_3$: ______, $\theta_4$: ______, $S_\theta$: ______

$\Delta E_\theta = (E_U - E_L)(S_\theta)$: ______

$H_{1/3}$: ______

LAG:

$L_o$: ______

$T_U$: ______, $E_U = \Delta E_\theta$: ______

$H_{1/3}$: ______

### MOVING (WINDWARD) FETCH

SEA:

Dist P to Leading Edge: ______

$T_U$: ______, $E_U = \Delta E_\theta$: ______

$H_{1/3}$: ______

SWELL:

$R_o$: ______

$T_U$: ______, $E_U$: ______

$T_L$: ______, $E_L$: ______

$\theta_3$: ______, $\theta_4$: ______, $S_\theta$: ______

$\Delta E_\theta = (E_U - E_L)(S_\theta)$: ______

$H_{1/3}$: ______

Figure 5. Sea and Swell Forecast Worksheet.

## 16. Example Forecasts

Example forecasts, made for three synoptic fetch models, are organized in the format of Section 13 (Forecasting Procedures) with correspondingly numbered steps. Each step is amplified by reference to a figure or table from which the information is obtained.

16.1 Example Forecast No. 1: Stationary Fetch Model

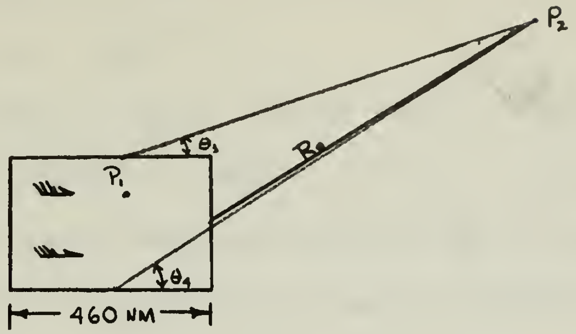



Figure 6. Geographic Positions of $P_1$ and $P_2$ Relative to a Stationary Fetch.

Fig. 6 portrays a fetch located in one geographic position for a period of at least 60 hours. From the synoptic and prognostic weather charts and Fig. 6 the following preliminary information is obtained for the forecast:

1. the positions of $P_1$ and $P_2$;
2. V = 35 knots beginning at 192100Z;
3. a Stationary Fetch Model.

Proceeding with the steps as outlined in Section 13.2:

a. Sea Forecast for $P_1$ at 220000Z; $t_{ob}$ = 60 hrs.

1. Distance from the windward edge to $P_1$ = 275 NM
2. $T_U$ = 12 sec. (FOPRIME graph; Fig. 7)
3. $T_L = 0$; $E_L = 0$.
4. $E_U = 64.0$ (Table 2)
5. $\Delta E_\theta = 64.0$
6. $H_{1/3} = 2.83\sqrt{64} = 2.83(8) = 22.6$ ft. (Table 3)

b. Swell Forecast for $P_2$ at 220000Z; $t_{ob}$ = 60 hrs.

1. No fetch limitation on highest period generated. (See Note 1)
2. $R_o$ = 700NM (Fig. 6)
3. $T_U = 19$; $T_L = 12$ (SWELL graph: Fig. 8)

4. $E_U = 128$; $E_L = 64$ (Table 2)

5. $\theta_3 = +20^\circ$; $\theta_4 = +40^\circ$ (Fig. 6)

6. $S_\theta = .18$ (Table 1)

7. $\Delta E_\theta = (E_U - E_L)(S_\theta) = (128-64)(.18) = 64(.18) = 11.5$

8. $H_{1/3} = 2.83\sqrt{11.5} = 2.83(3.4) = 9.6$ ft. (Table 3)

Note 1: If the fetch length were only 400 NM the building of waves would be limited so that $T_{FU}$ would be 16 seconds (FOPRIME graph: Fig. 7). Then $T_U = T_{FU} = 16$ seconds at $P_2$ and $H_{1/3} = 7.6$ ft.

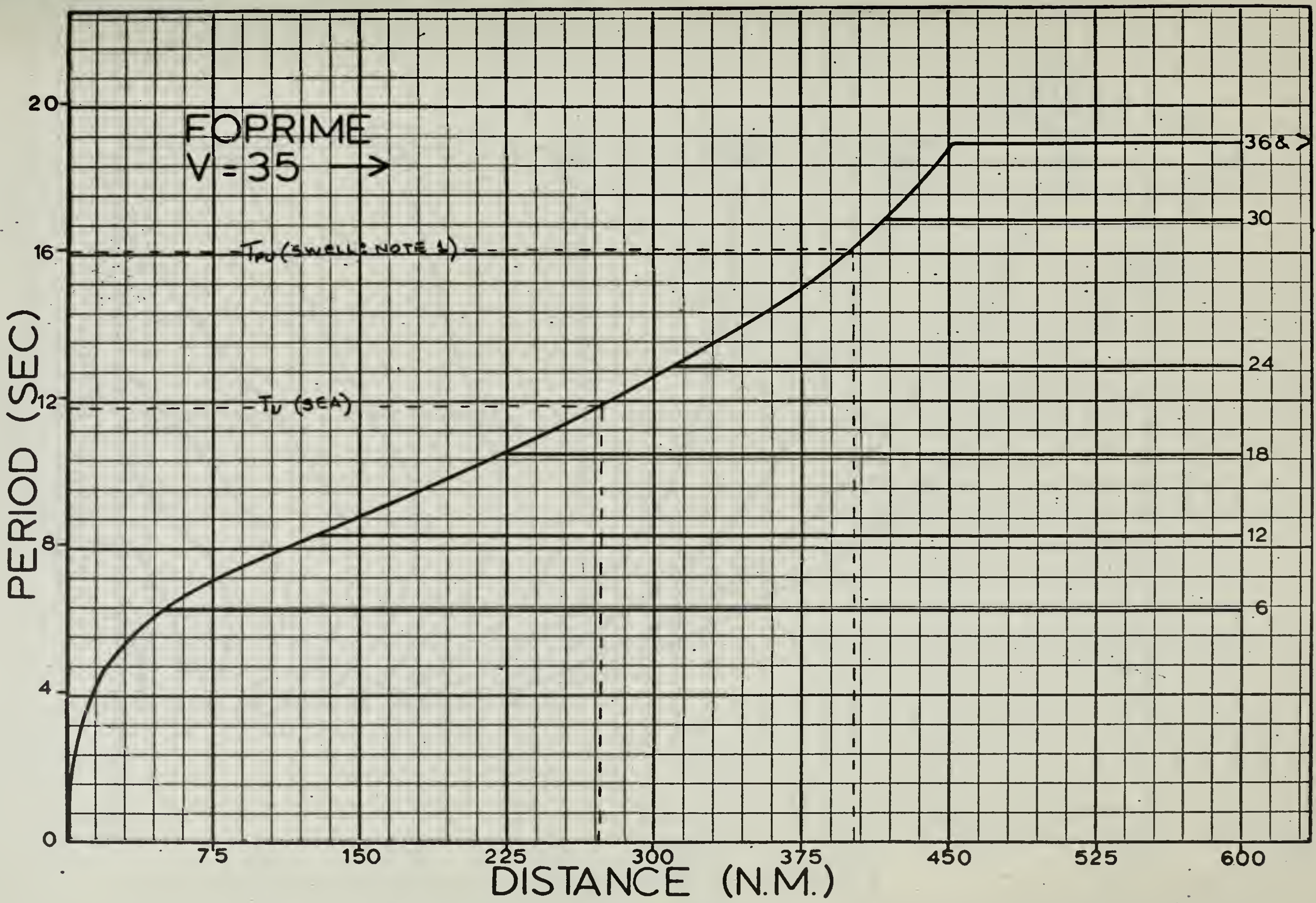

FOPRIME
V=35 →
$T_{PV}$ (SWELL: NOTE 1)
$T_V$ (SEA)
36 & >
30
24
18
12
6
20
16
12
8
4
0
PERIOD (SEC)
75
150
225
300
375
450
525
600
DISTANCE (N.M.)

Figure 7.

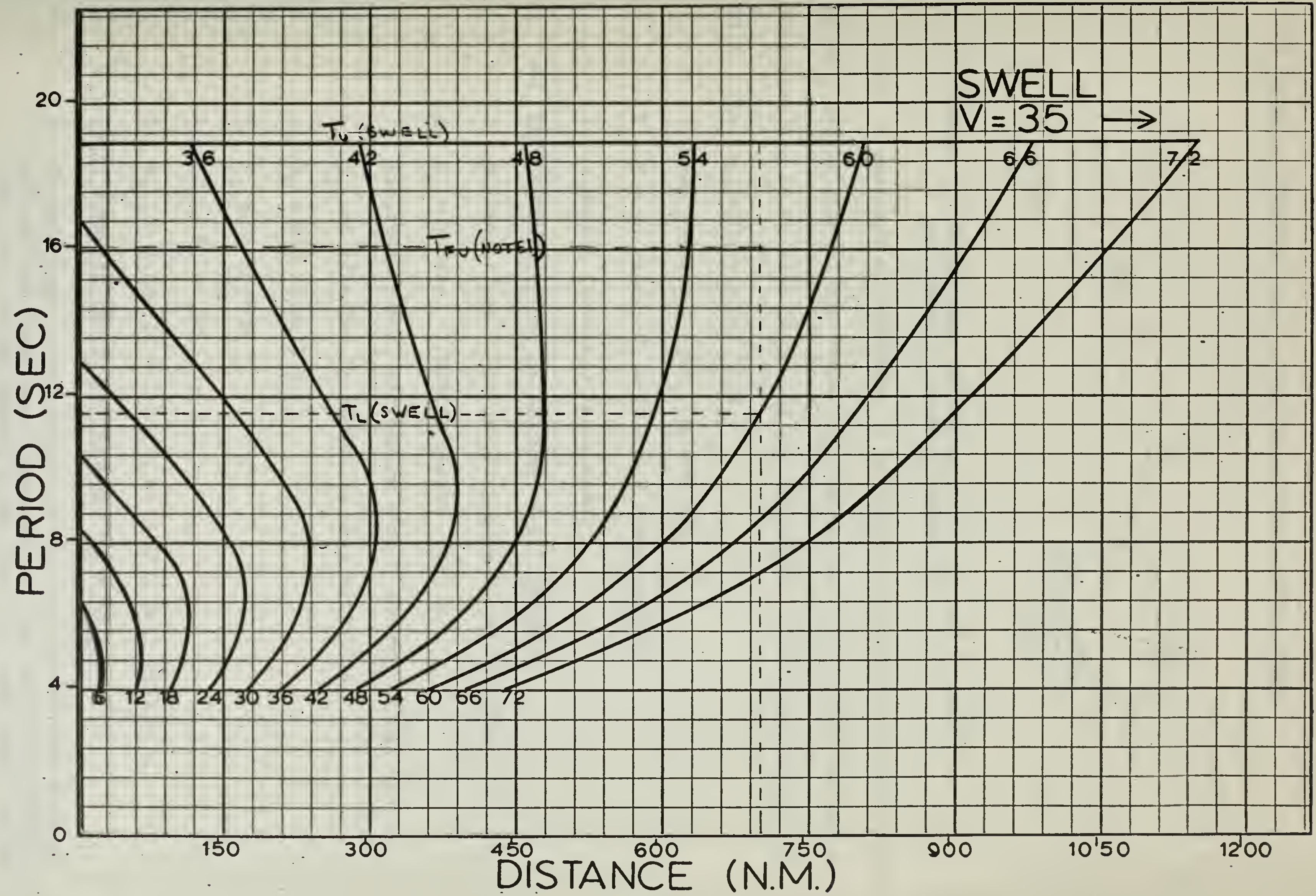

SWELL
V = 35
$T_U$ (SWELL)
$T_{FU}$ (NOTE 1)
$T_L$ (SWELL)
36
42
48
54
60
66
72
6 12 18 24 30 36 42 48 54 60 66 72
PERIOD (SEC)
0
4
8
12
16
20
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)

Figure 8.

16.2 Example Forecast No. 2: Moving (leeward) Fetch Model

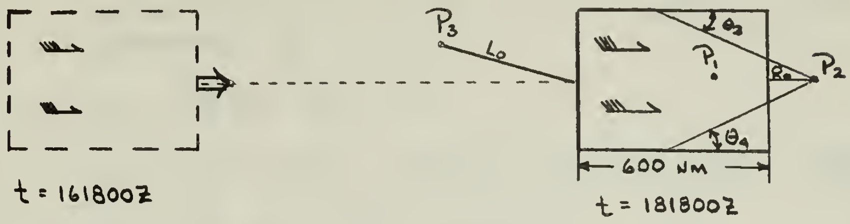



Figure 9. Geographic Positions of $P_1$, $P_2$ and $P_3$ Relative to a Moving (leeward) Fetch.

Fig. 9 portrays the movement of a fetch from the time the wind began blowing to the time of the forecast, showing the three points for which forecasts are to be made following the procedure as outlined in Section 13.3. The preliminary steps show:

1. the positions of $P_1$, $P_2$ and $P_3$;
2. $V = 40$ knots; $V_f = 15$ knots since 161800Z;
3. a Moving (leeward) Fetch Model.

a. Sea Forecast for $P_1$ at 181800Z: $t_{ob} = 48$ hrs.

1. Distance from $P_1$ to trailing edge = 450 NM (Fig. 9)
2. $T_U = 14$ sec. (FOPRIME graph: Fig. 10)
3. Distance from $P_1$ to leading edge = 150 NM (Fig. 9)
4. $P_1$ not affected by SUMDEL in this situation.
5. $E_U = 130$ (Table 2)
6. $T_L = 0$; $E_L = 0$
7. $\Delta E_\theta = E_U = 130$
8. $H_{1/3} = 2.83\sqrt{130} = 2.83(11.4) = 32.2$ ft. (Table 3)

b. Swell Forecast for $P_2$ at 181800Z: $t_{ob} = 48$ hrs.

1. To determine if the length of the fetch limits the highest wave period which can be generated enter both the FOPRIME graph (Fig. 10) and the SUMDEL graph (Fig. 11) with fetch length and obtain:

$T_{FU}$ = 18 sec. (FOPRIME graph)

$T_{FU}$ = 22 sec. (SUMDEL graph)

Using the smaller of the two, the highest possible wave period generated, $T_{FU}$ = 18 sec.

2. $R_o$ = 100 NM (Fig. 9)

3. $T_U = T_{FU}$ = 18 sec. (Step 1) ; $T_L$ = 14 sec. (SWELL graph: Fig. 12 )

4. $E_U$ = 205; $E_L$ = 130. (Table 2)

5. $\theta_3 = +30^o$; $\theta_4 = -30^o$; $S_\theta$ = .6 (Fig. 9 and Table 1)

6. $\Delta E_\theta$ = (205-130) (.6) = 45.0

7. $H_{1/3} = 2.83\sqrt{45}$ = 19 ft. (Table 3)

c. <u>Swell Forecast for $P_3$ at 181800Z: $t_{ob}$ = 48 hrs.</u>

1. $L_o$ = 400 NM (Fig. 9)

2. $T_U$ = 6 sec. (LAG graph: Fig. 13)

3. $T_L$ = 0; $E_L$ = 0.

4. $E_U$ = 7.8 (Table 2)

5. $E_\theta = E_U$ = 7.8

6. $H_{1/3} = 2.83\sqrt{7.8}$ = 7.9 ft. (Table 3)

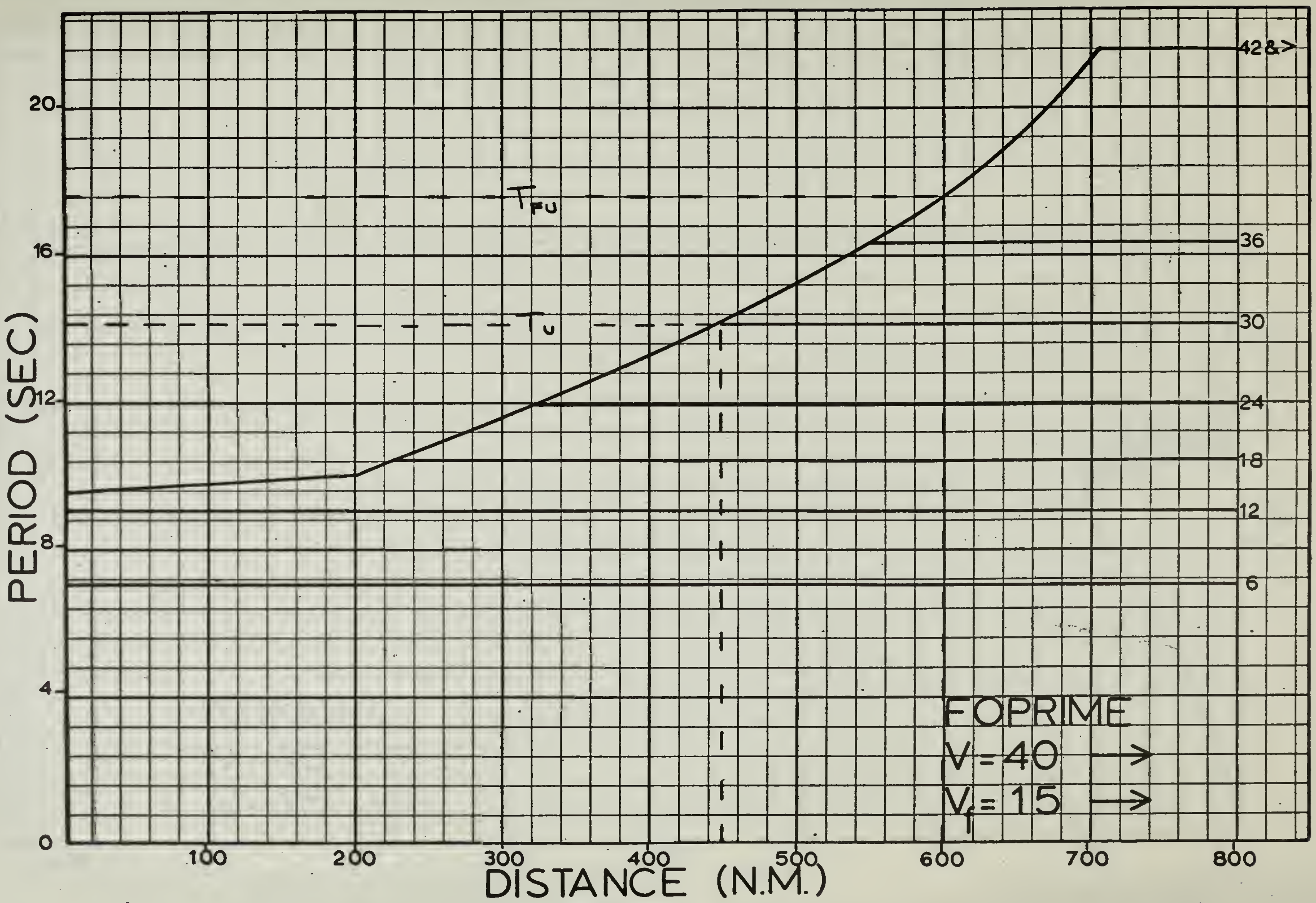
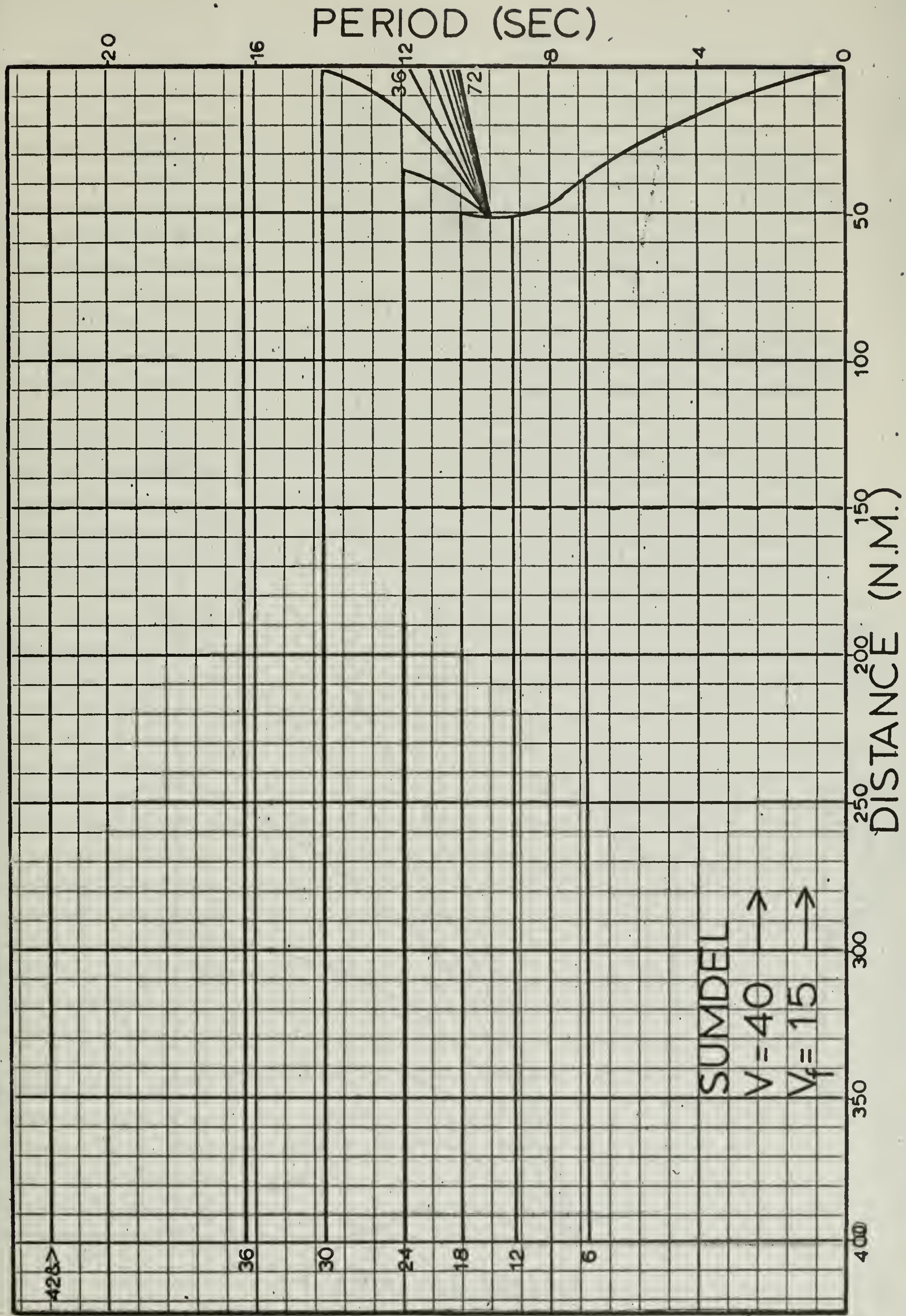

PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
100
200
300
400
500
600
700
800
$T_{FU}$
$T_U$
42&>
36
30
24
18
12
6
FOPRIME
V=40 →
$V_f$=15 →

Figure 10.



PERIOD (SEC)
20
16
12
8
4
0
36
72
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
SUMDEL
V = 40
V_f = 15
42
36
30
24
18
12
6


Figure 11.

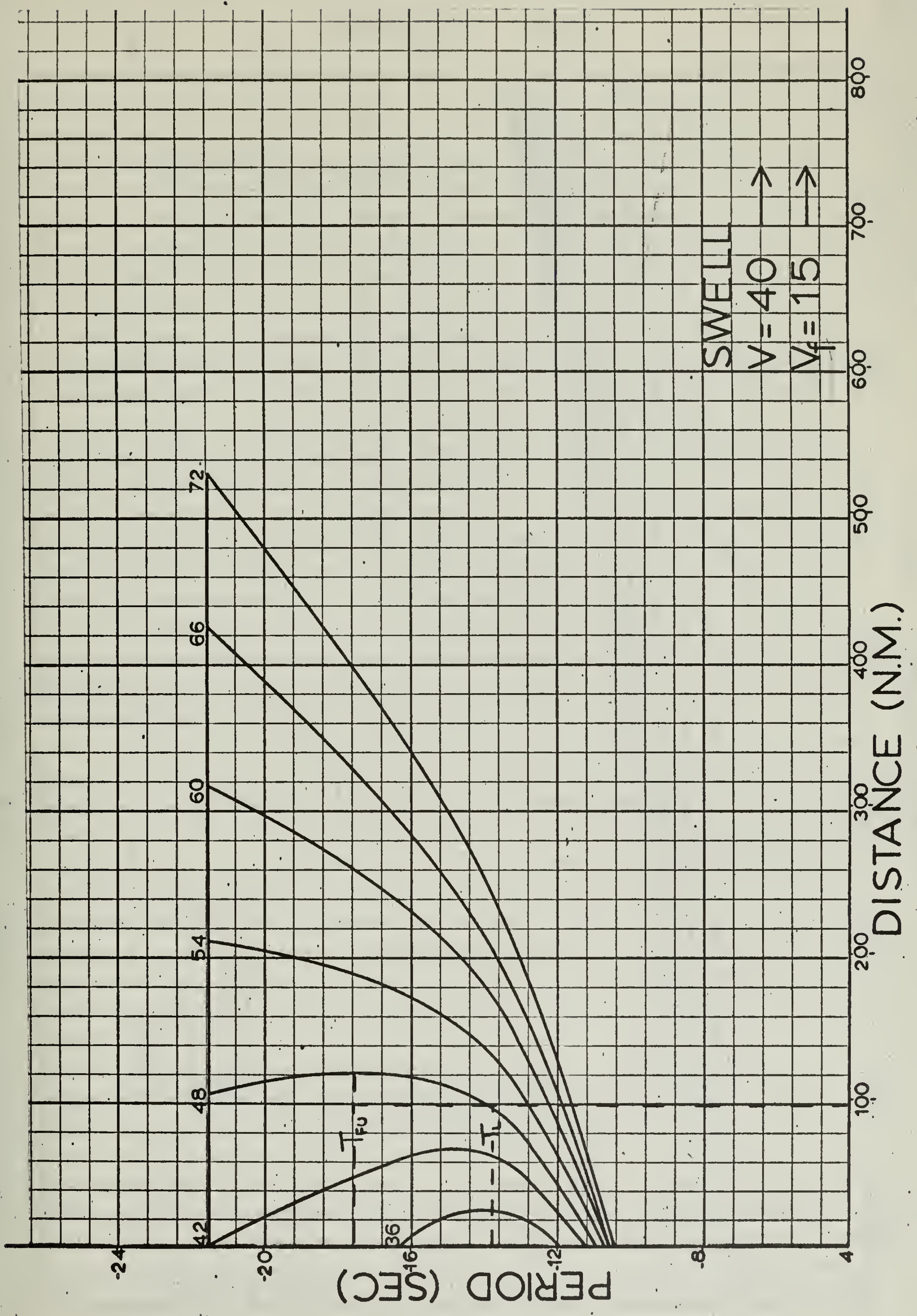
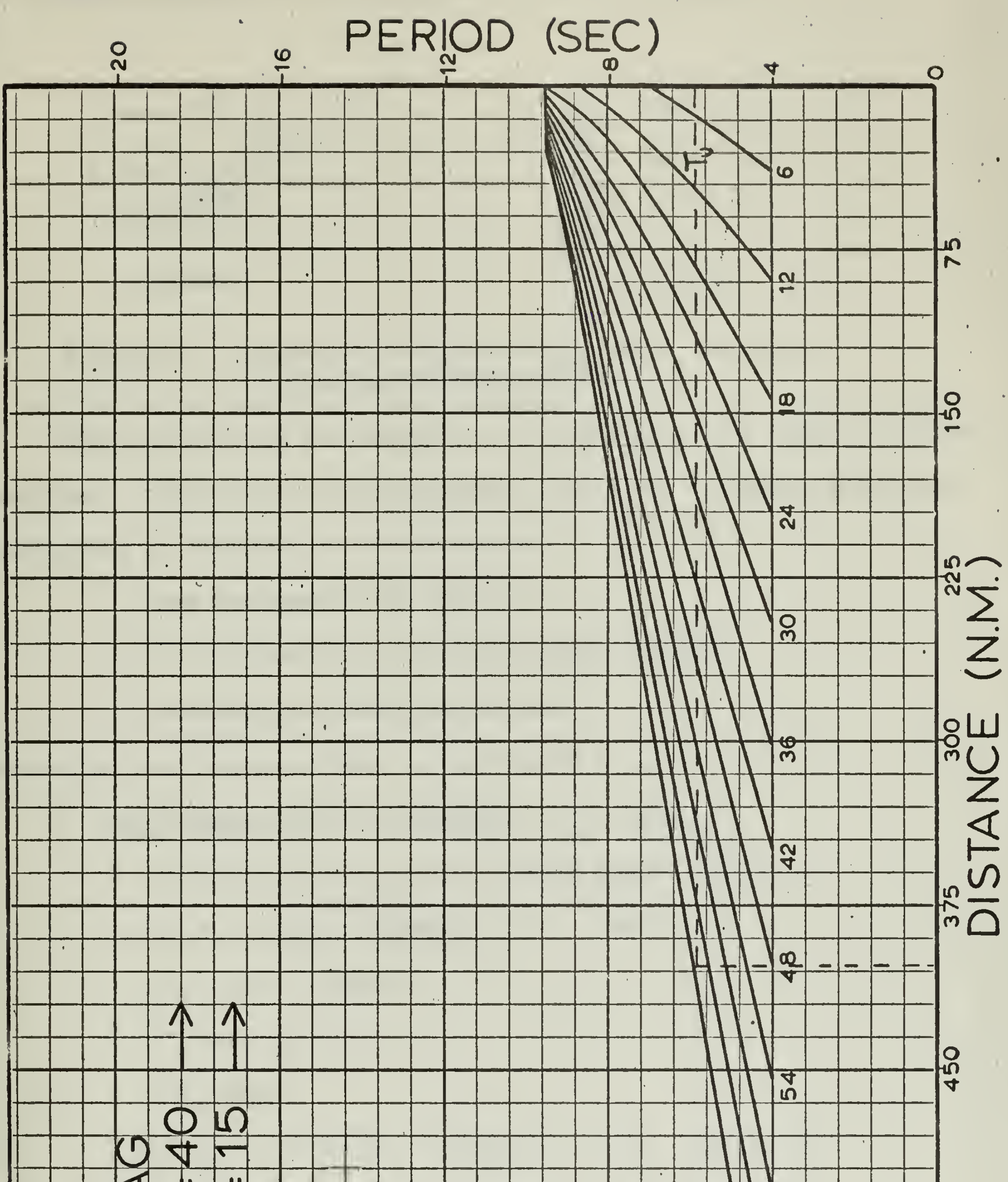

SWELL
V = 40
V_f = 15
DISTANCE (N.M.)
PERIOD (SEC)
100
200
300
400
500
600
700
800
4
8
12
16
20
24
36
42
48
54
60
66
72
T_FU
T_L

Figure 12.



PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
75
150
225
300
375
450
525
600
6
12
18
24
30
36
42
48
54
60
66
72
$T_v$
LAG
V = 40
$V_f$ = 15


Figure 13.

## 16.3 Example Forecast No. 3: Moving (windward) Fetch Model.

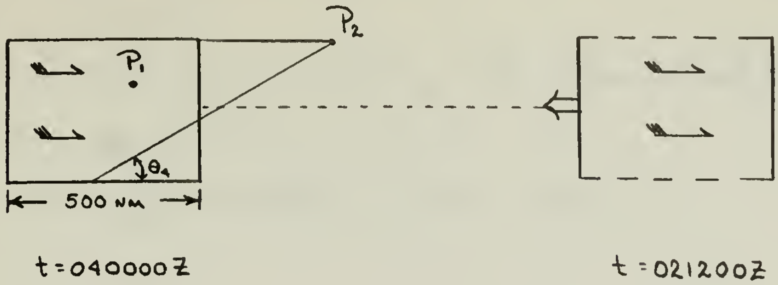



Figure 14. Geographic Positions of $P_1$ and $P_2$ Relative to a Moving (windward) Fetch

Fig. 14 portrays the movement of a generating area during the times indicated. From synoptic and prognostic charts the following preliminary information is obtained for the forecast:

1. the positions of $P_1$ and $P_2$;
2. $V = 30$ knots; $V_f = 20$ knots since 021200Z;
3. a Moving (windward) Fetch Model.

Proceeding with steps outlined in Section 13.4:

a. <u>Sea Forecast for $P_1$ at 040000Z; $t_{ob} = 36$ hrs.</u>

1. Distance from $P_1$ to the leading edge = 400 NM
2. $T_u = 9$ seconds (SUMDEL graph : Fig. 15)
3. $E_u = 21.0$ (Table 2)
4. $T_L = 0$; $E_L = 0$
5. $\Delta E_\theta = 21.0$
6. $H_{1/3} = 2.83\sqrt{21.0} = 2.83(4.6) = 13$ ft. (Table 3)

b. <u>Swell Forecast for $P_2$ at 040000Z; $t_{ob} = 36$ hrs.</u>

1. $T_{FU} = 10$ seconds (SUMDEL graph: Fig. 15)
2. $R_o = 450$ NM (Fig. 14)
3. $T_U = T_{FU} = 10$ seconds (SUMDEL graph: Fig. 15 and SWELL graph: Fig. 16)

   $T_L = 0$

4. $E_U = 29.0$; (Table 2)

$E_L = 0$

5. $\theta_3 = 0$, $\theta_4 = +40^\circ$, $S_\theta = .38$ (Fig. 14 and Table 1)

6. $\Delta E_\theta = (29)(.38) = 11.0$

7. $H_{1/3} = 2.83\sqrt{11.0} = 9.3$ ft. (Table 3)

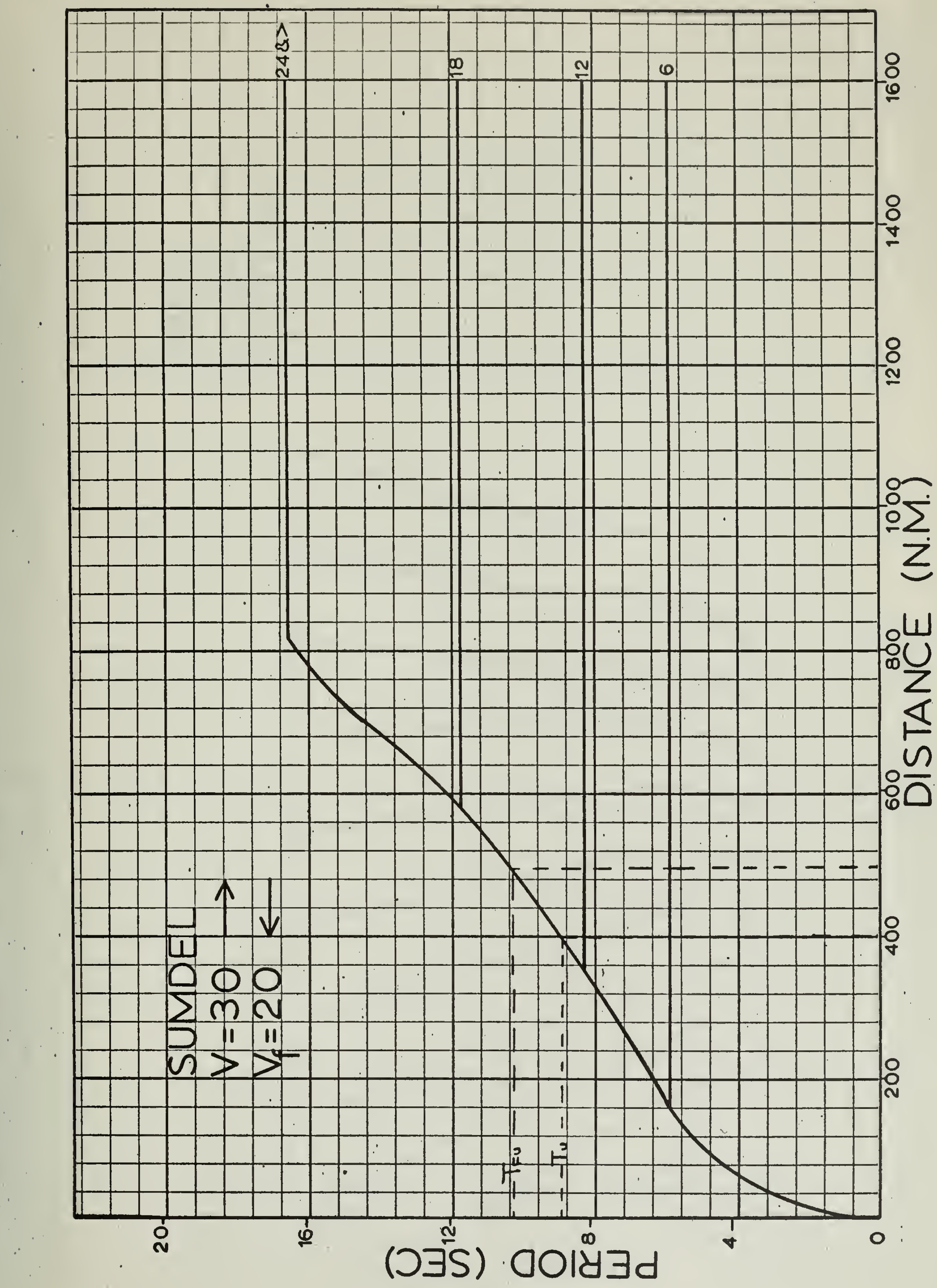
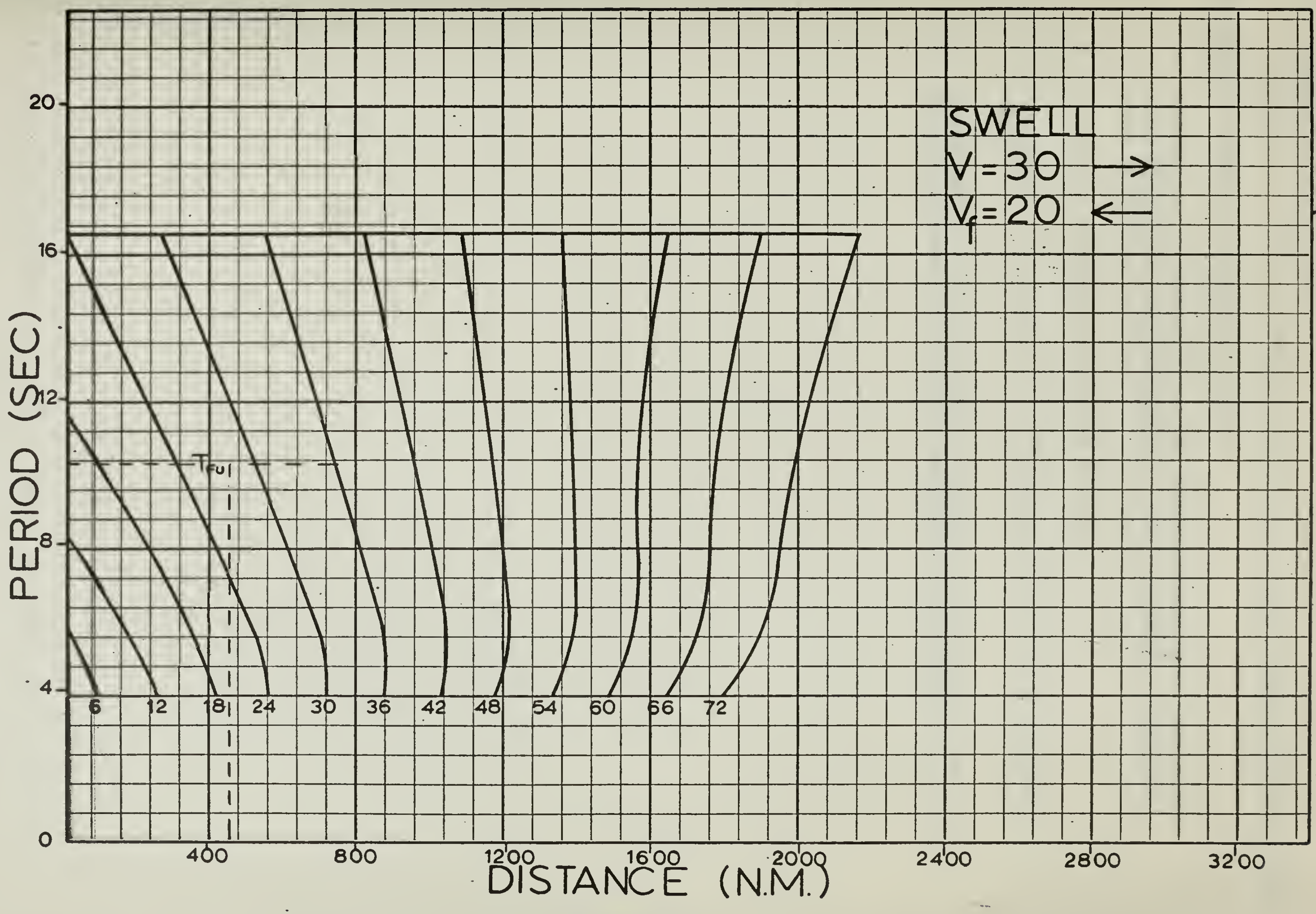

SUMDEL
V=30
$V_f$=20
24&>
18
12
6
$T_{FU}$
$T_U$
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600

Figure 15.



SWELL
V = 30
$V_f$ = 20
$T_{FU}$
PERIOD (SEC)
20
16
12
8
4
0
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)


Figure 16.

## 17. Further Investigations

Following is a list of subjects which the authors hope to study further as time and computer facilities permit:

1. completion of models where the wind is blowing at some angle with respect to the direction of fetch movement other than zero or $180^{\circ}$;

2. extending the duration beyond 72 hours;

3. completion of a model for a dying sea and one with variable winds;

4. programming in SCRAP computer language for adaptation to U. S. Navy Fleet Numerical Weather Facility forecasting.

18. <u>Graphs</u>

Included in this section are the graphs of LAG, FOPRIME, SUMDEL and SWELL, divided into sub-sections:

18.1 Stationary Fetch Model; pages 44-62

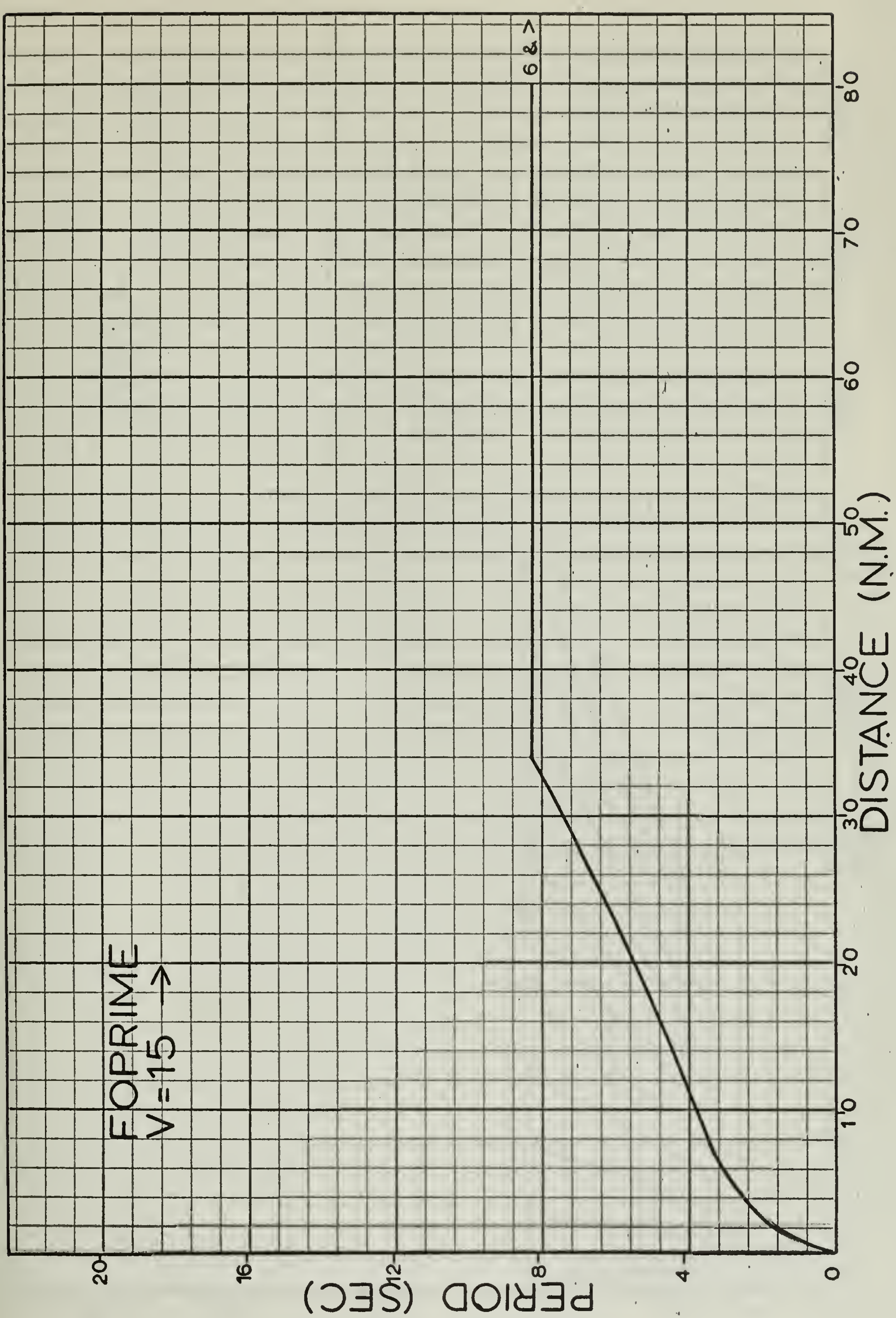
18.2 Moving (leeward) Fetch Model; pages 63-212

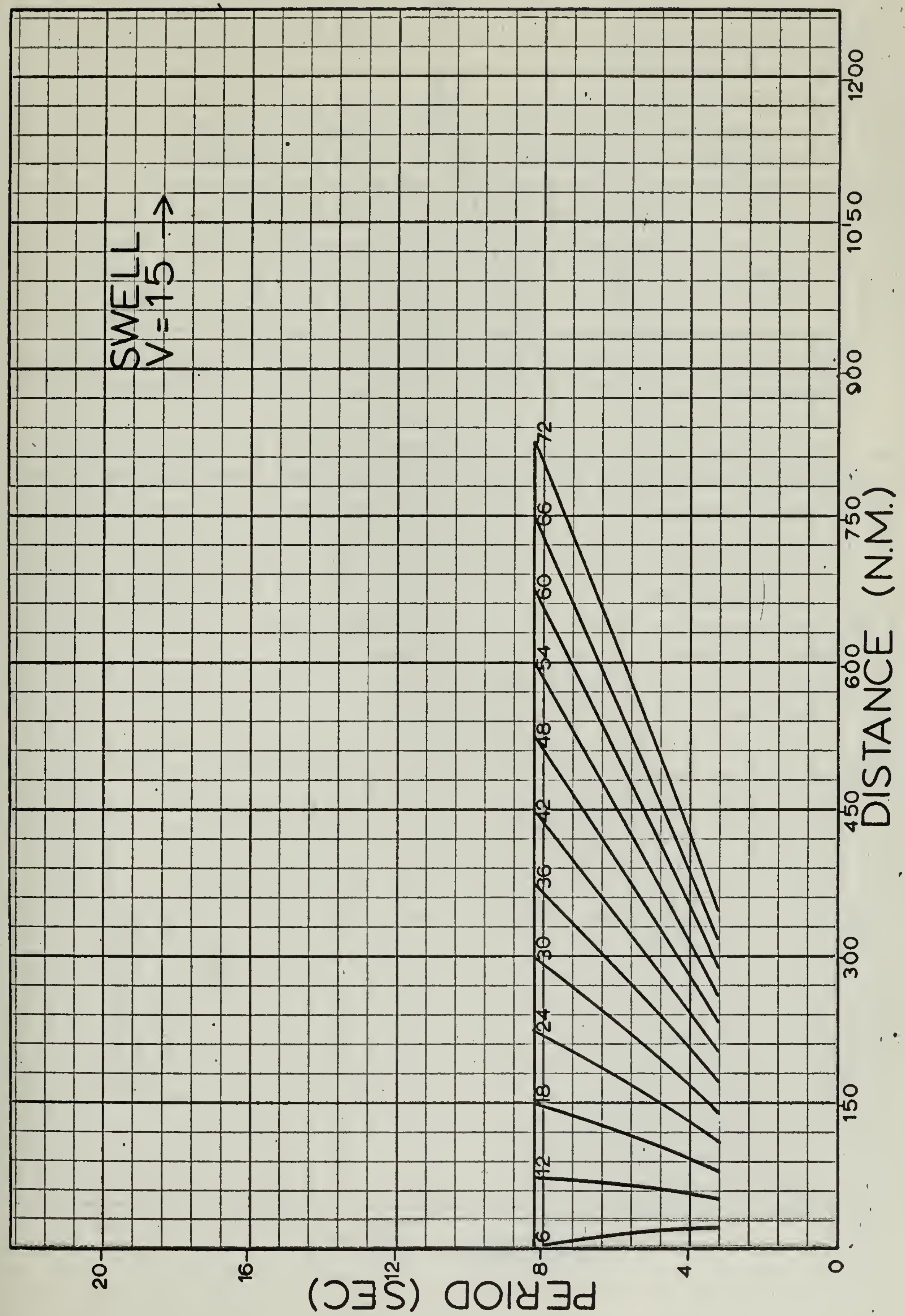
18.3 Moving (windward) Fetch Model; pages 213-303

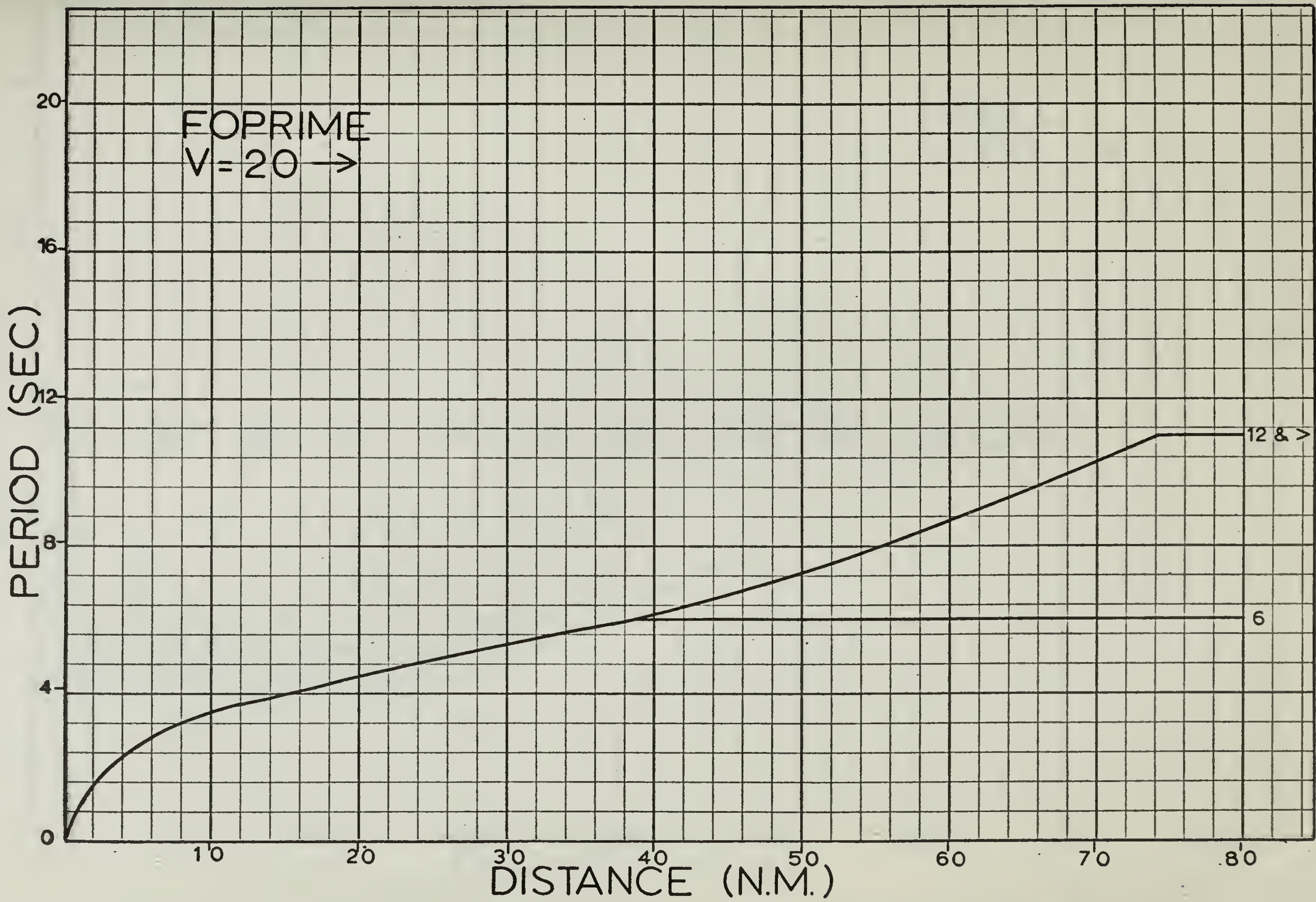
The graphs within the sub-sections are arranged by increasing wind speeds and associated increasing fetch speeds.

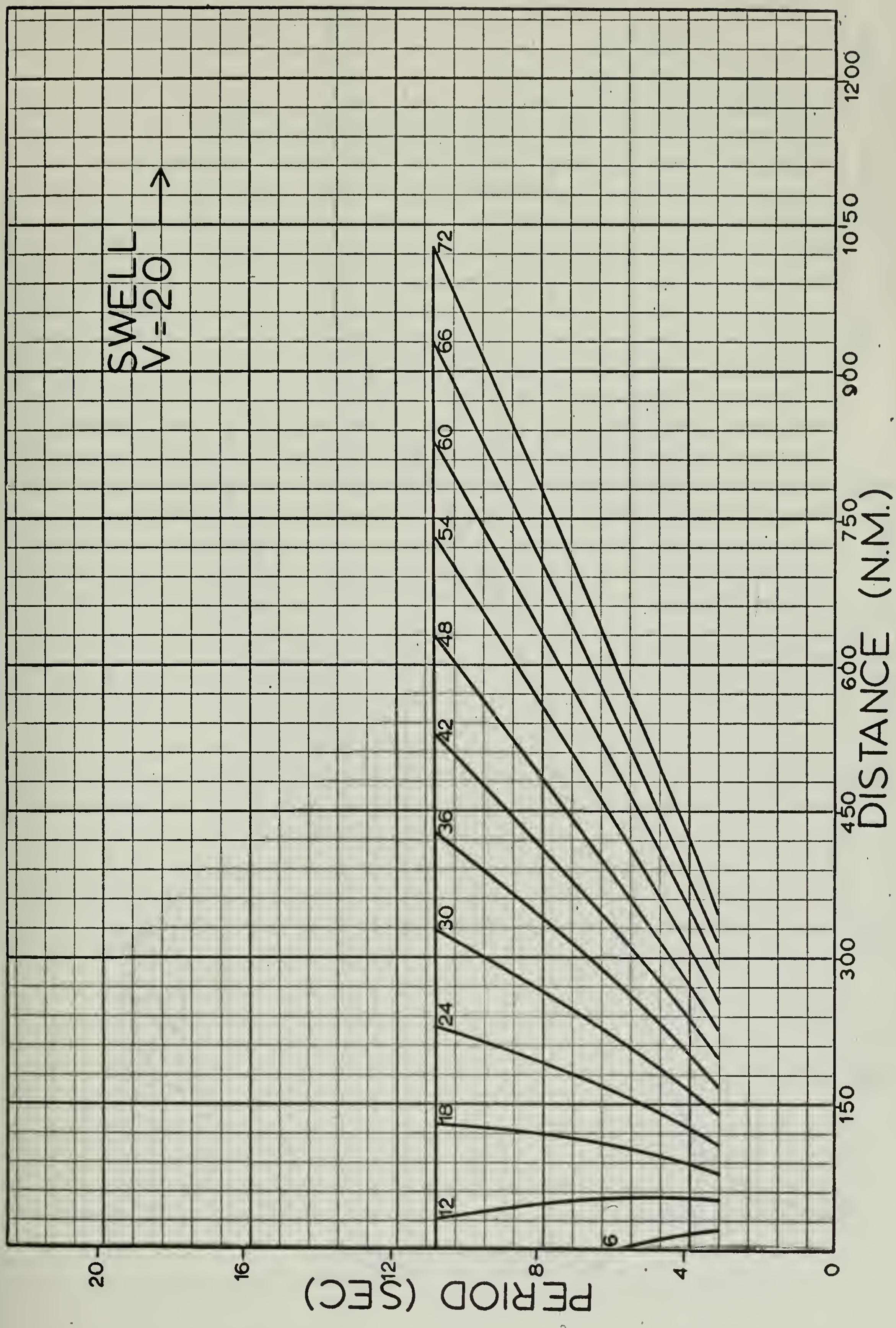
18.1 Stationary Fetch Model Graphs

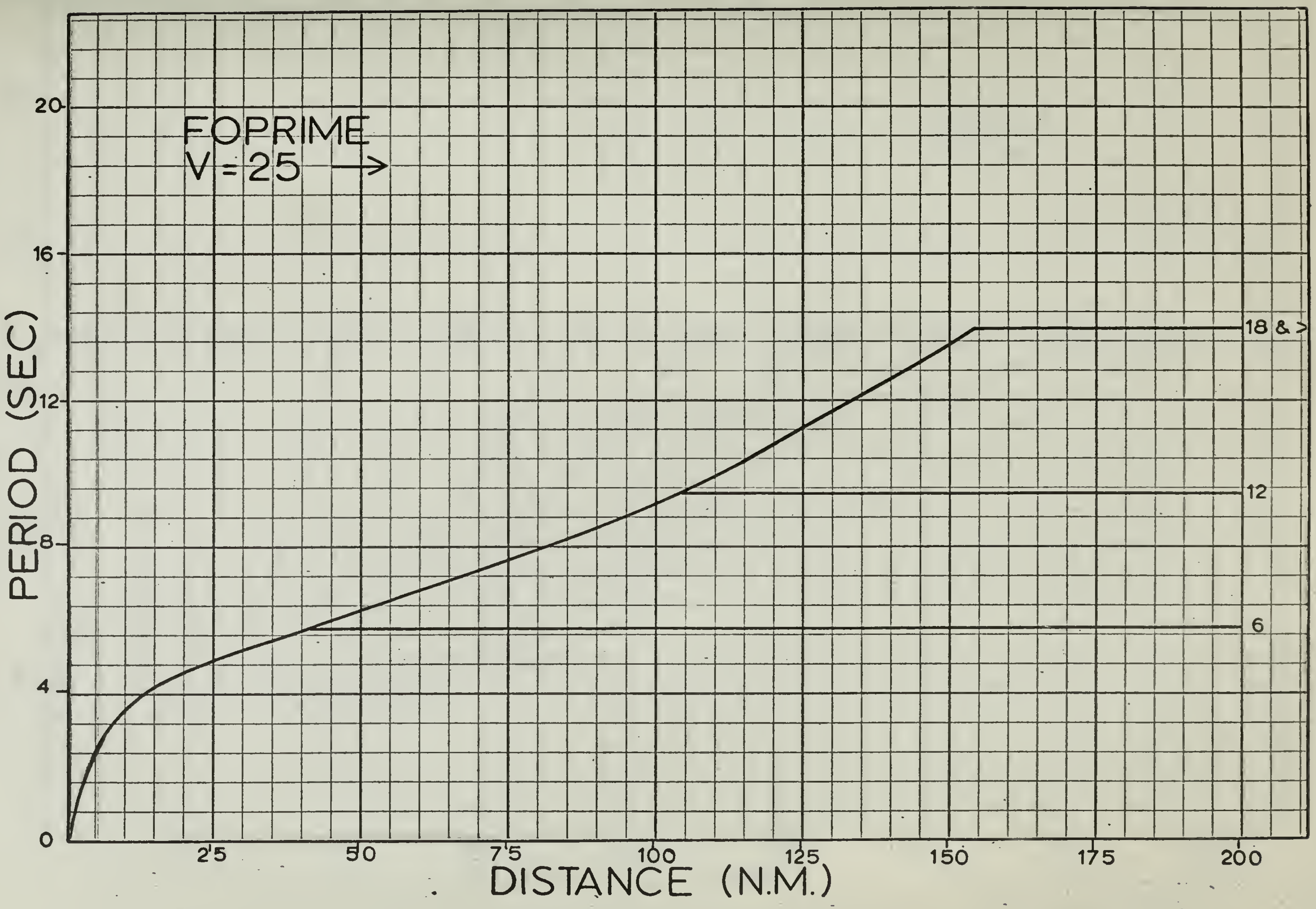
INDEX OF GRAPHS

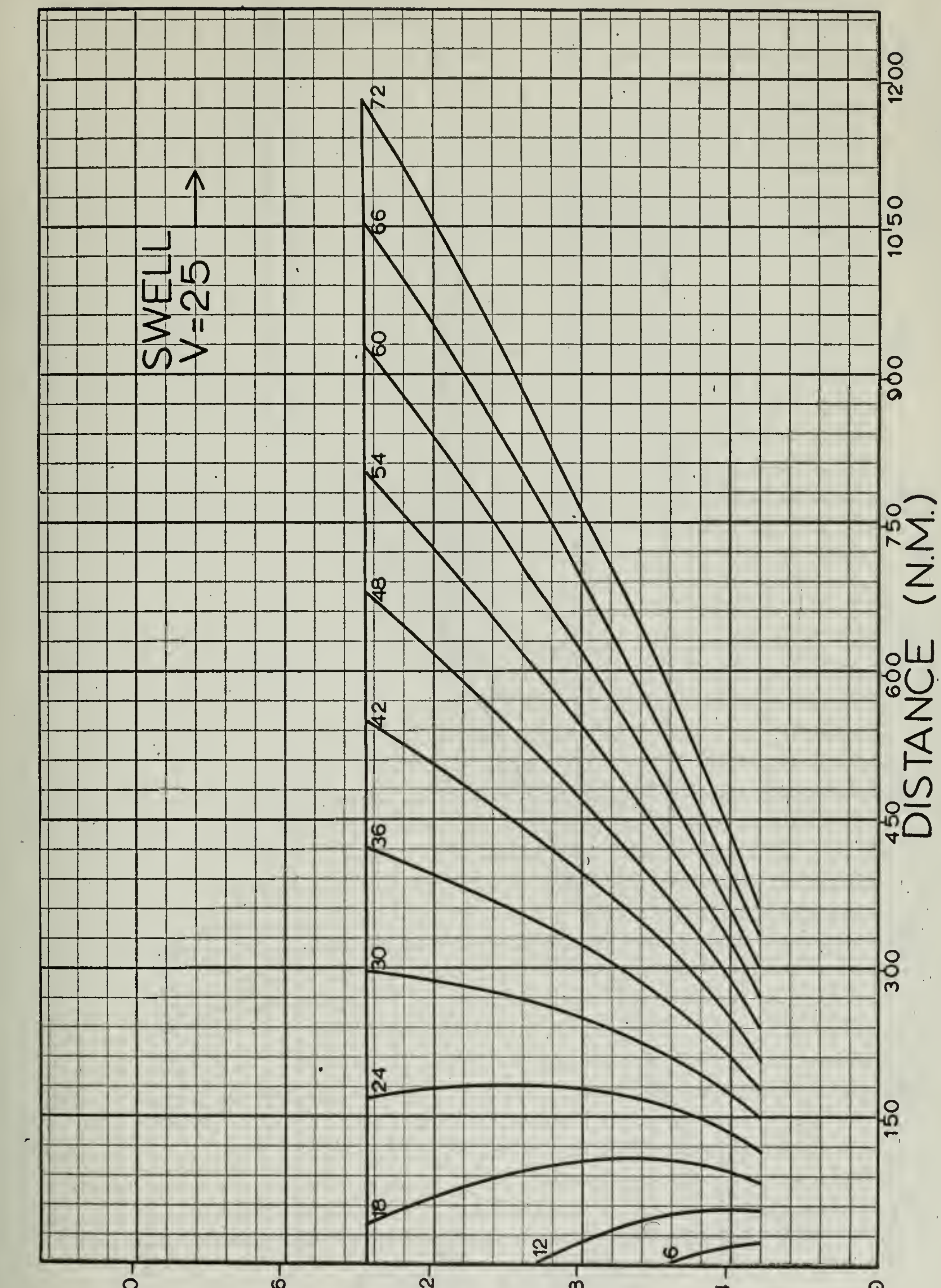

FOPRIME
V = 15 →
6 & >
DISTANCE (N.M.)
PERIOD (SEC)

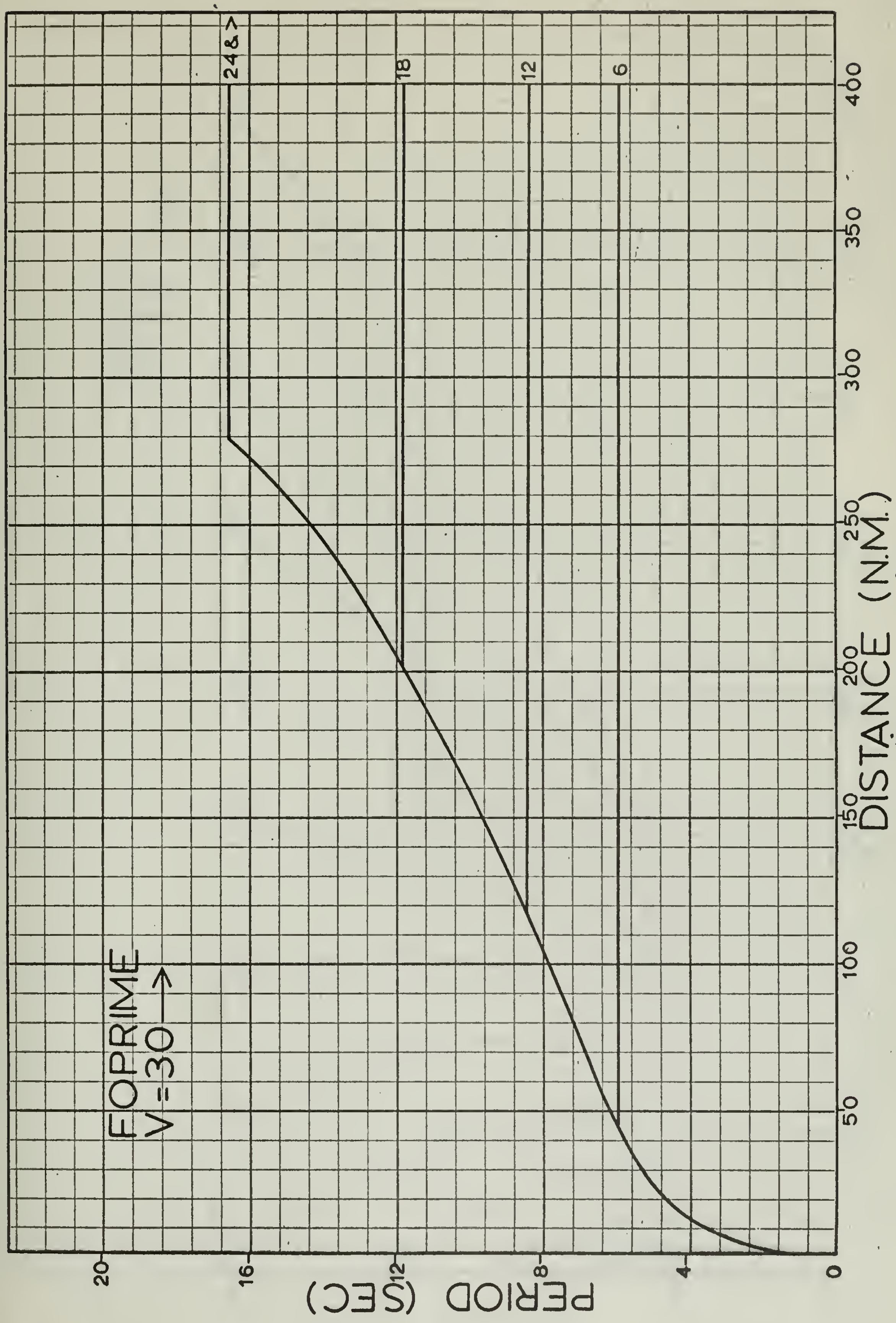

SWELL
V = 15 →
DISTANCE (N.M.)
0
150
300
450
600
750
900
1050
1200
PERIOD (SEC)
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72

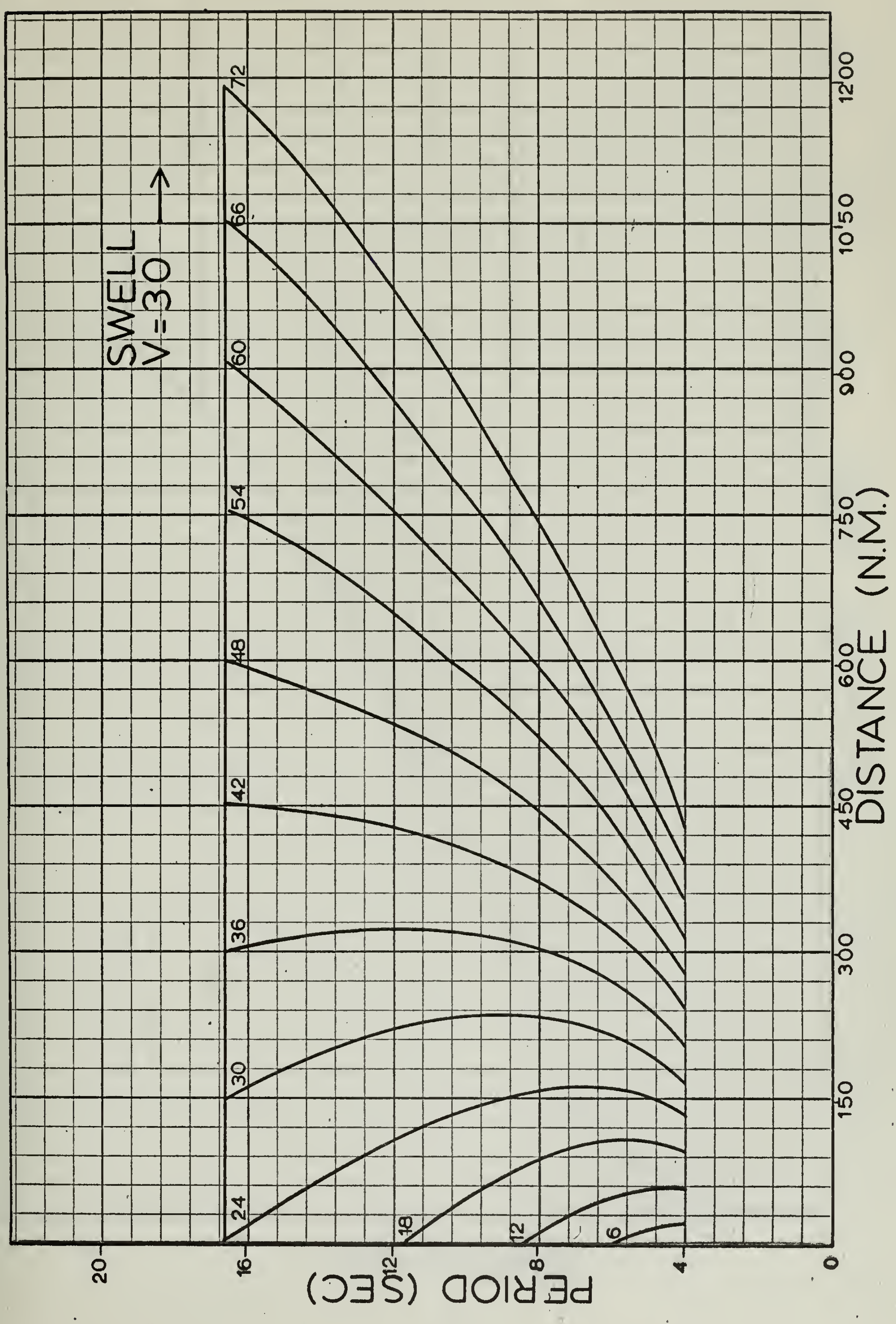

FOPRIME
V = 20 →
PERIOD (SEC)
0
4
8
12
16
20
10
20
30
40
50
60
70
80
DISTANCE (N.M.)
12 & >
6

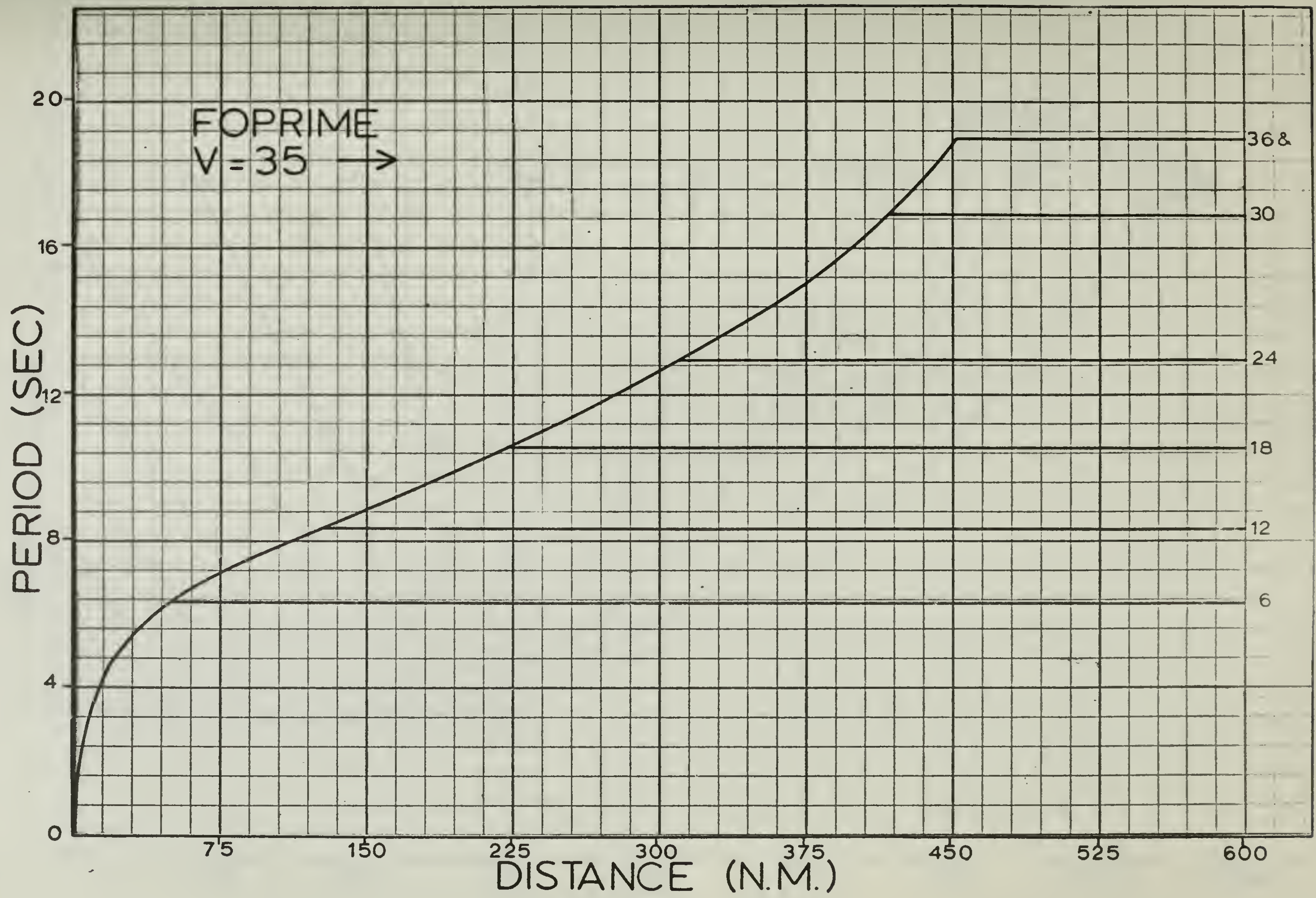

SWELL
V=20
DISTANCE (N.M.)
PERIOD (SEC)
0
150
300
450
600
750
900
1050
1200
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72

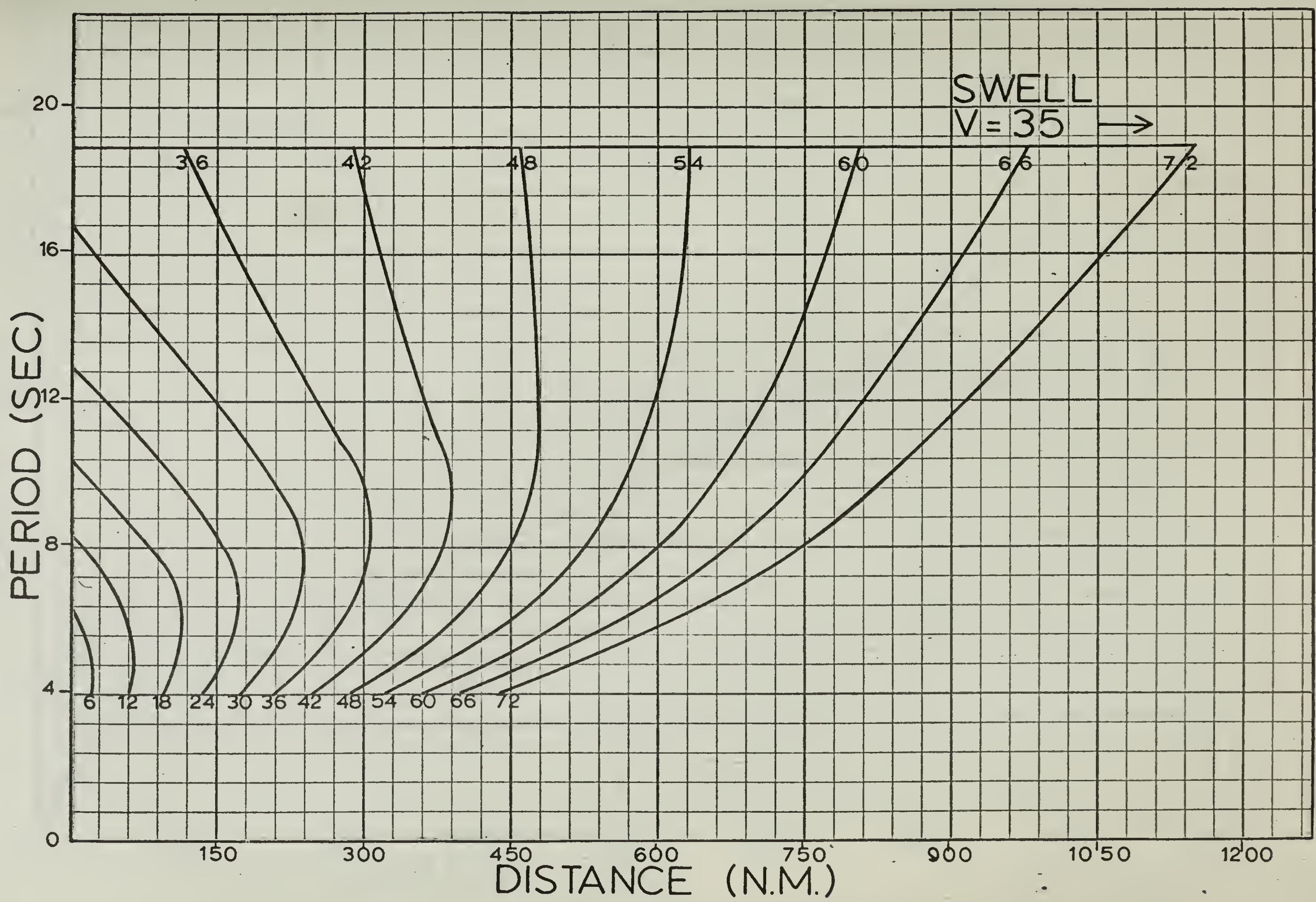

FOPRIME
V = 25
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
25
50
75
100
125
150
175
200
18 & >
12
6

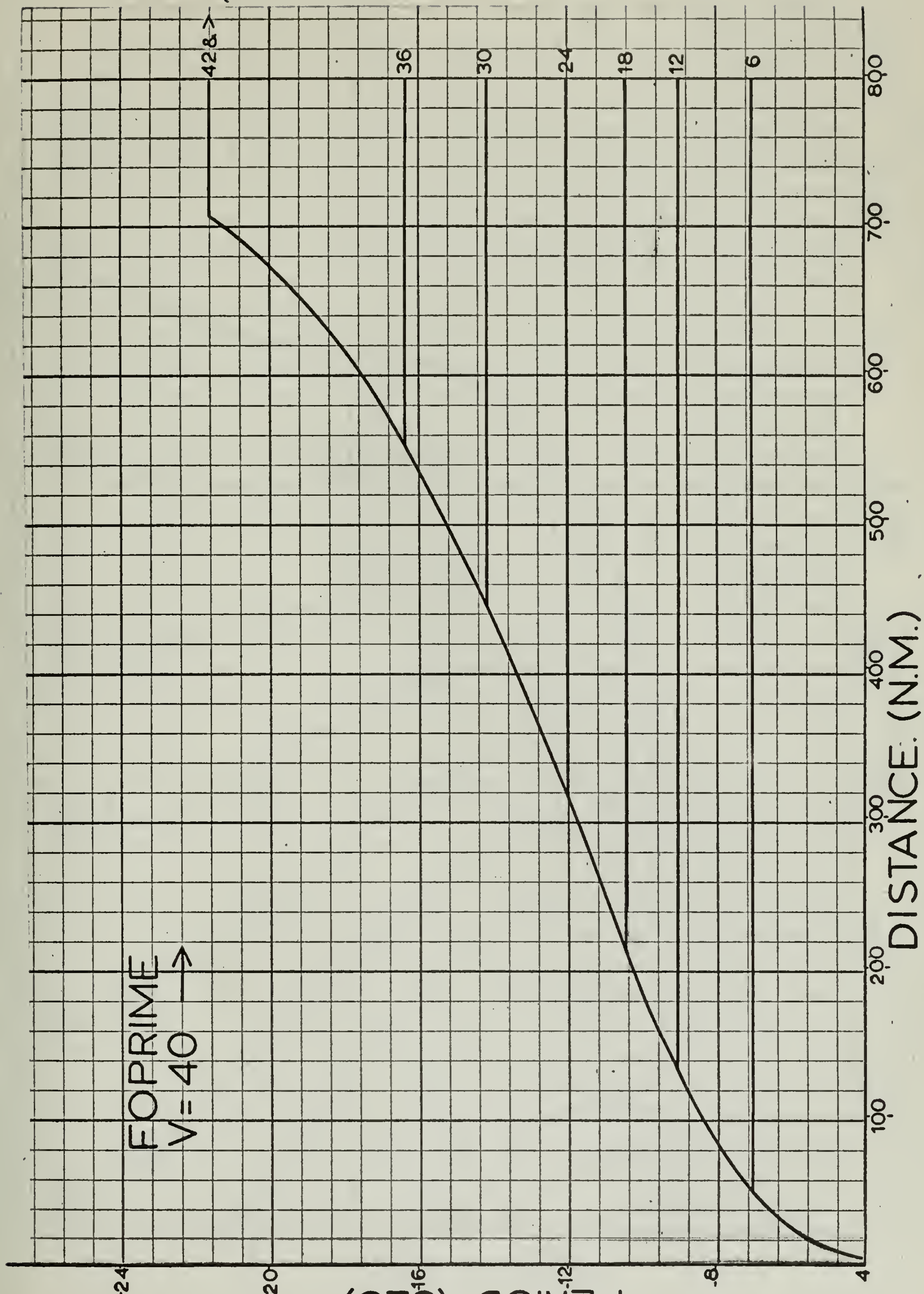

SWELL
V=25
DISTANCE (N.M.)
0
150
300
450
600
750
900
1050
1200
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72

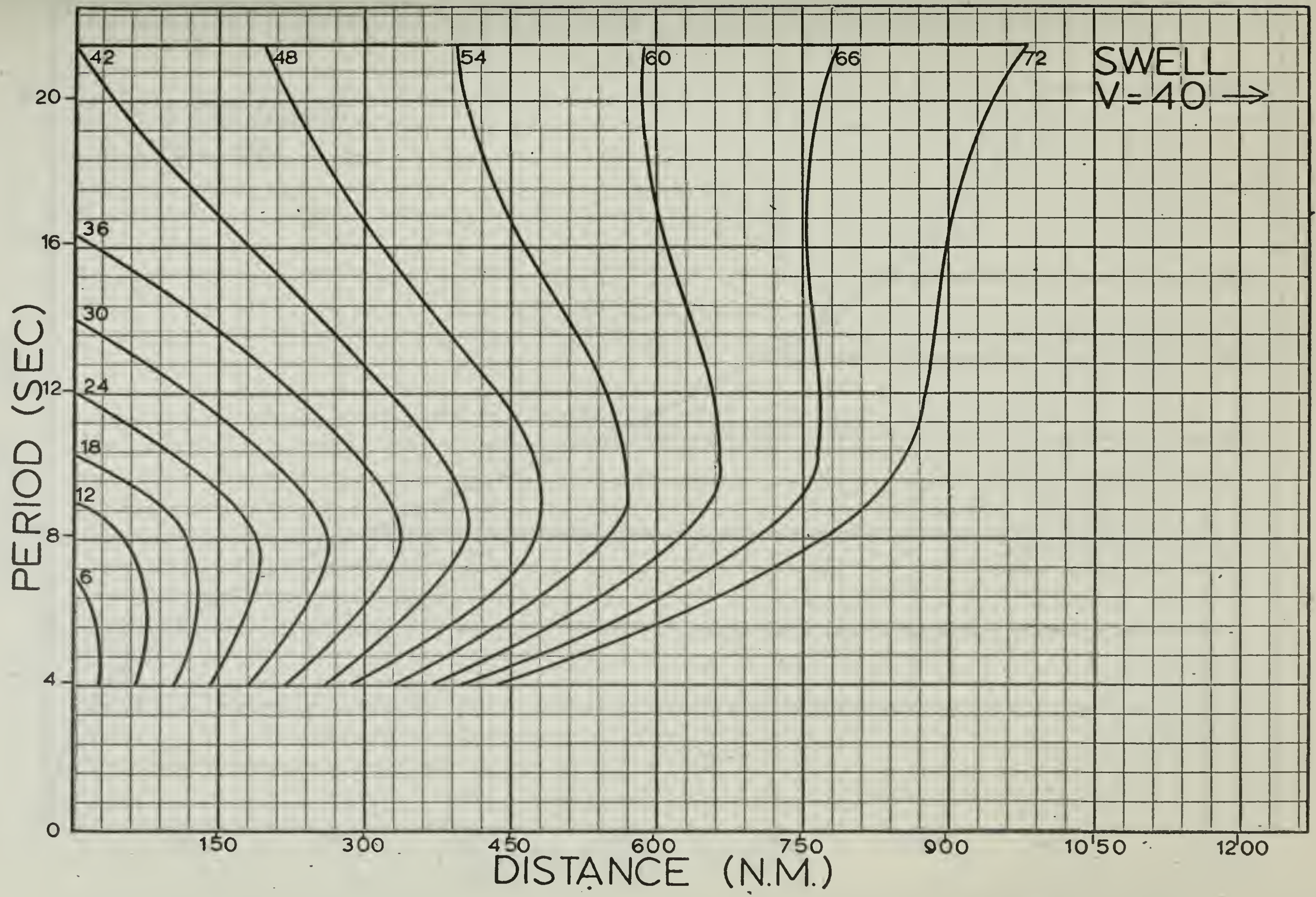

FOPRIME
V=30⟶
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
50
100
150
200
250
300
350
400
6
12
18
24&>

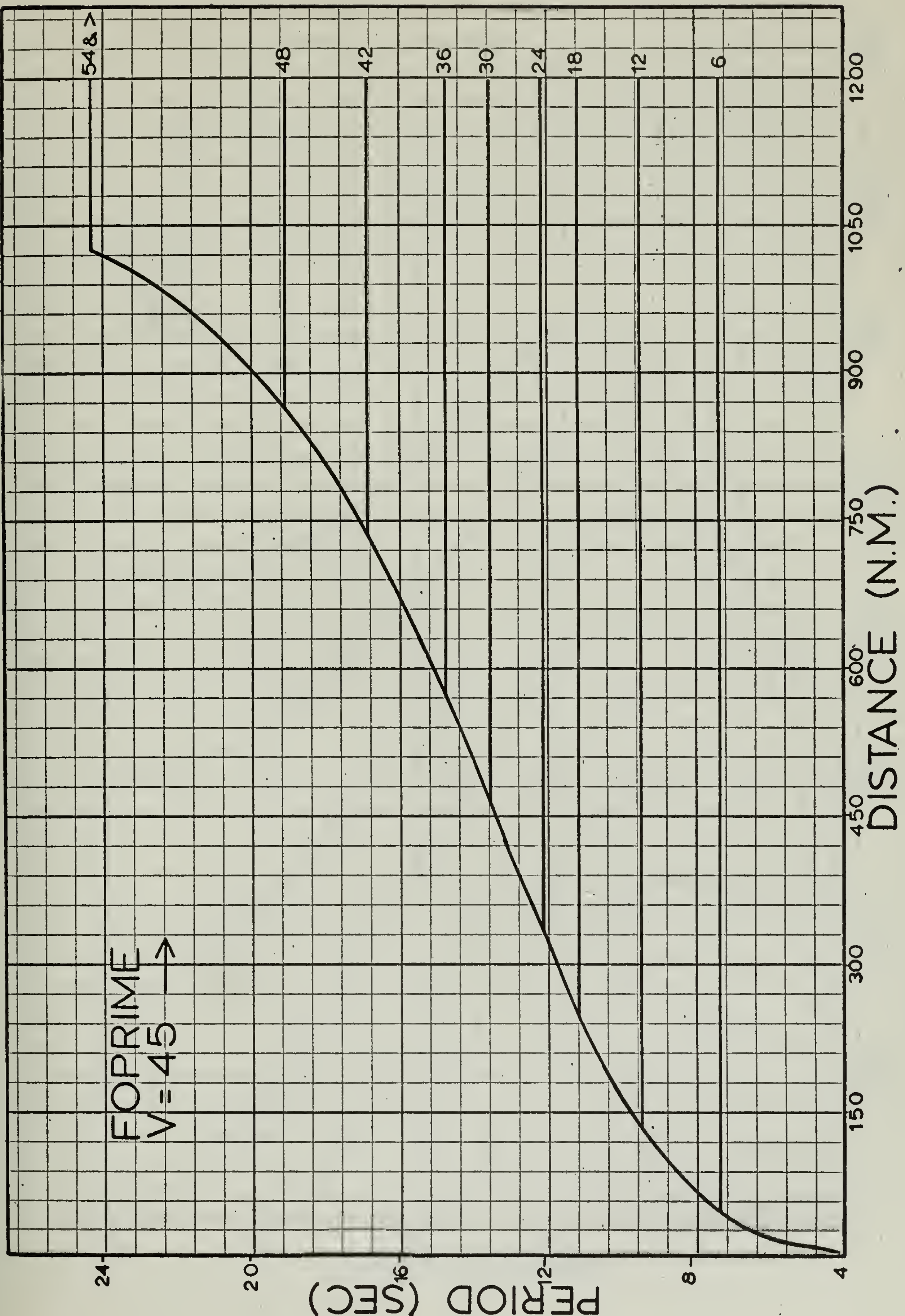

SWELL
V=30
DISTANCE (N.M.)
PERIOD (SEC)
0
150
300
450
600
750
900
1050
1200
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72

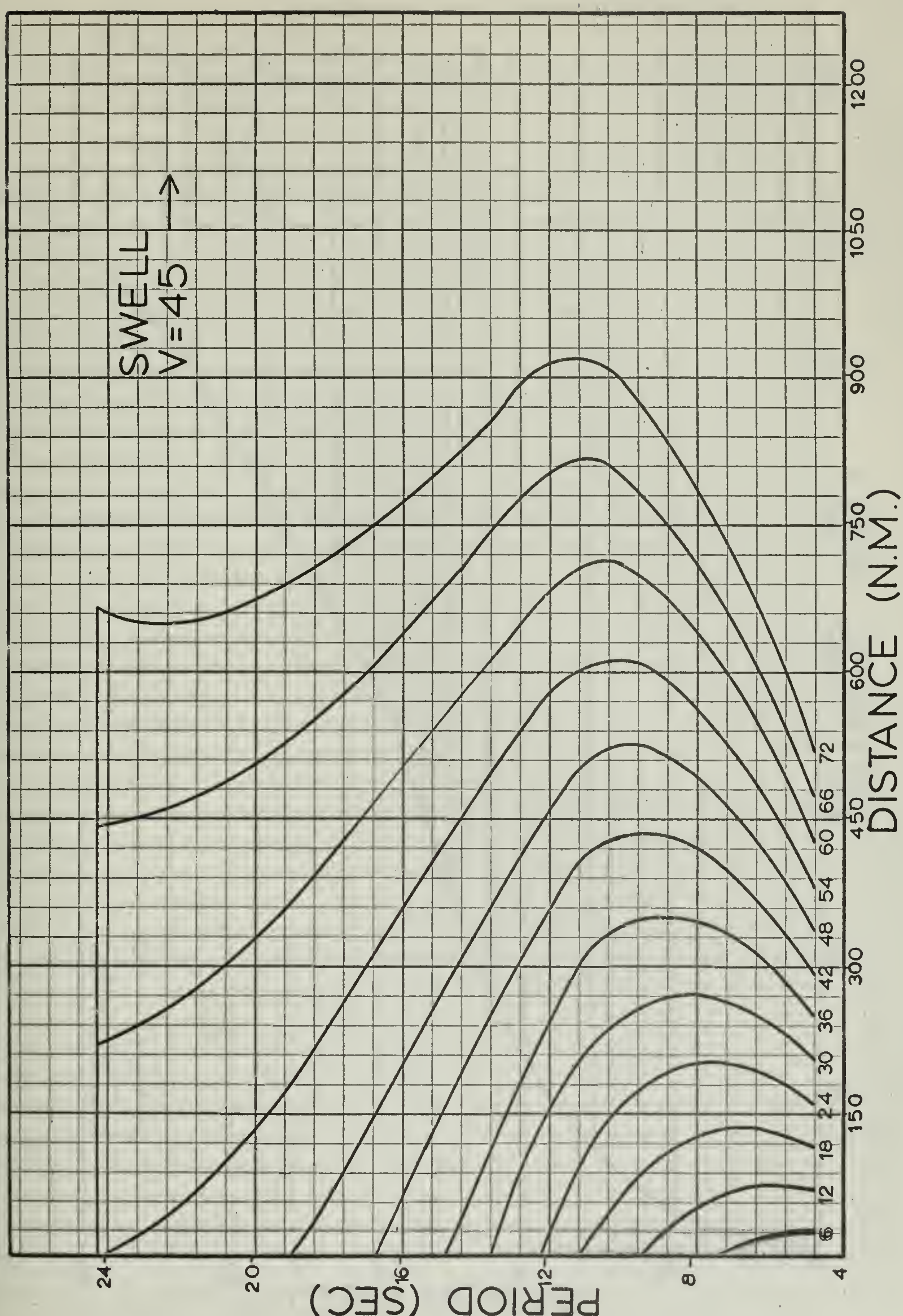

FOPRIME
V = 35 →
36&
30
24
18
12
6
PERIOD (SEC)
20
16
12
8
4
0
75
150
225
300
375
450
525
600
DISTANCE (N.M.)


SWELL
V = 35
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
150
300
450
600
750
900
1050
1200
6 12 18 24 30 36 42 48 54 60 66 72
36
42
48
54
60
66
72

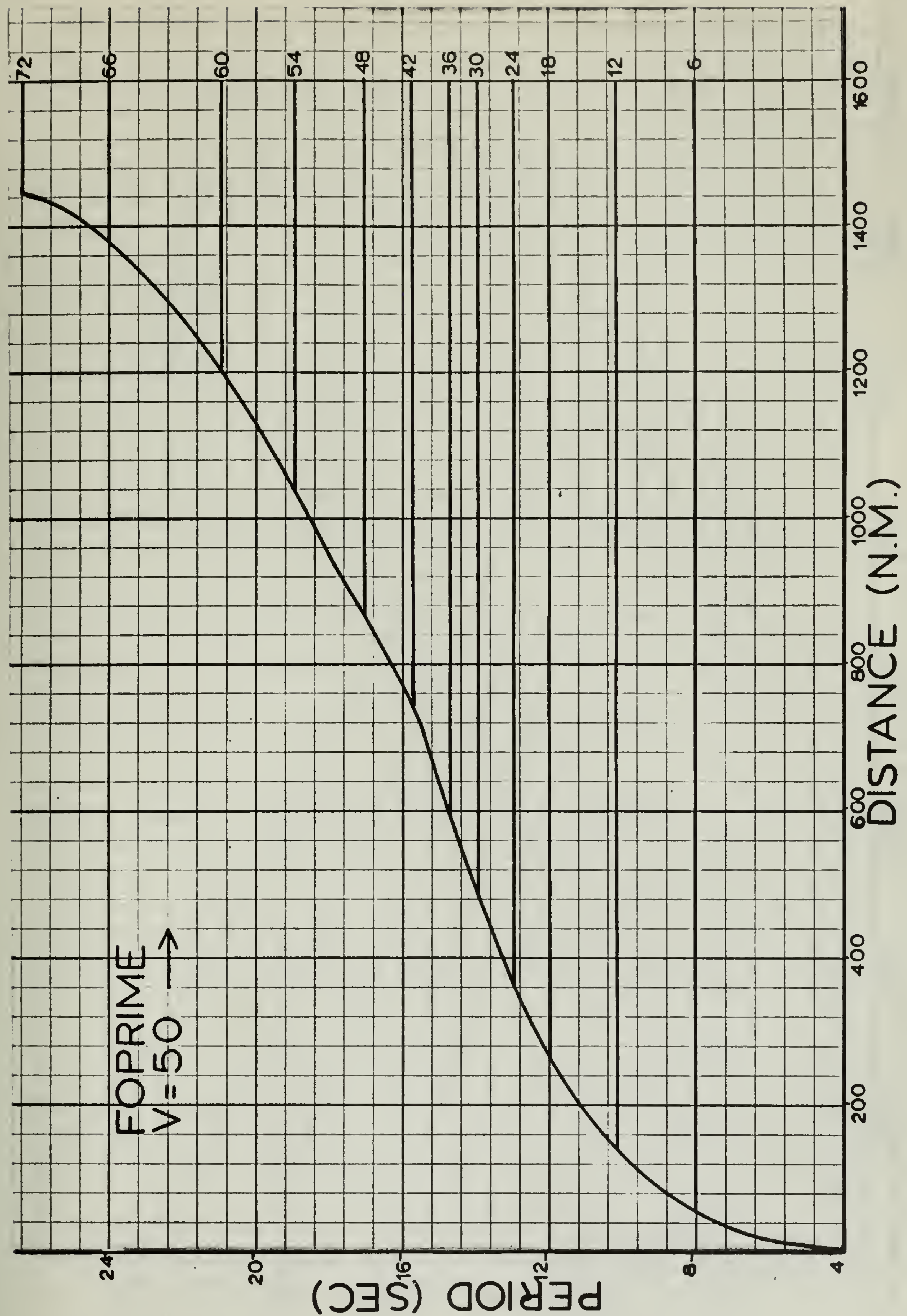

FOPRIME
V= 40
42 &
36
30
24
18
12
6
100
200
300
400
500
600
700
800
DISTANCE (N.M.)
4
8
12
16
20
24
PERIOD (SEC)

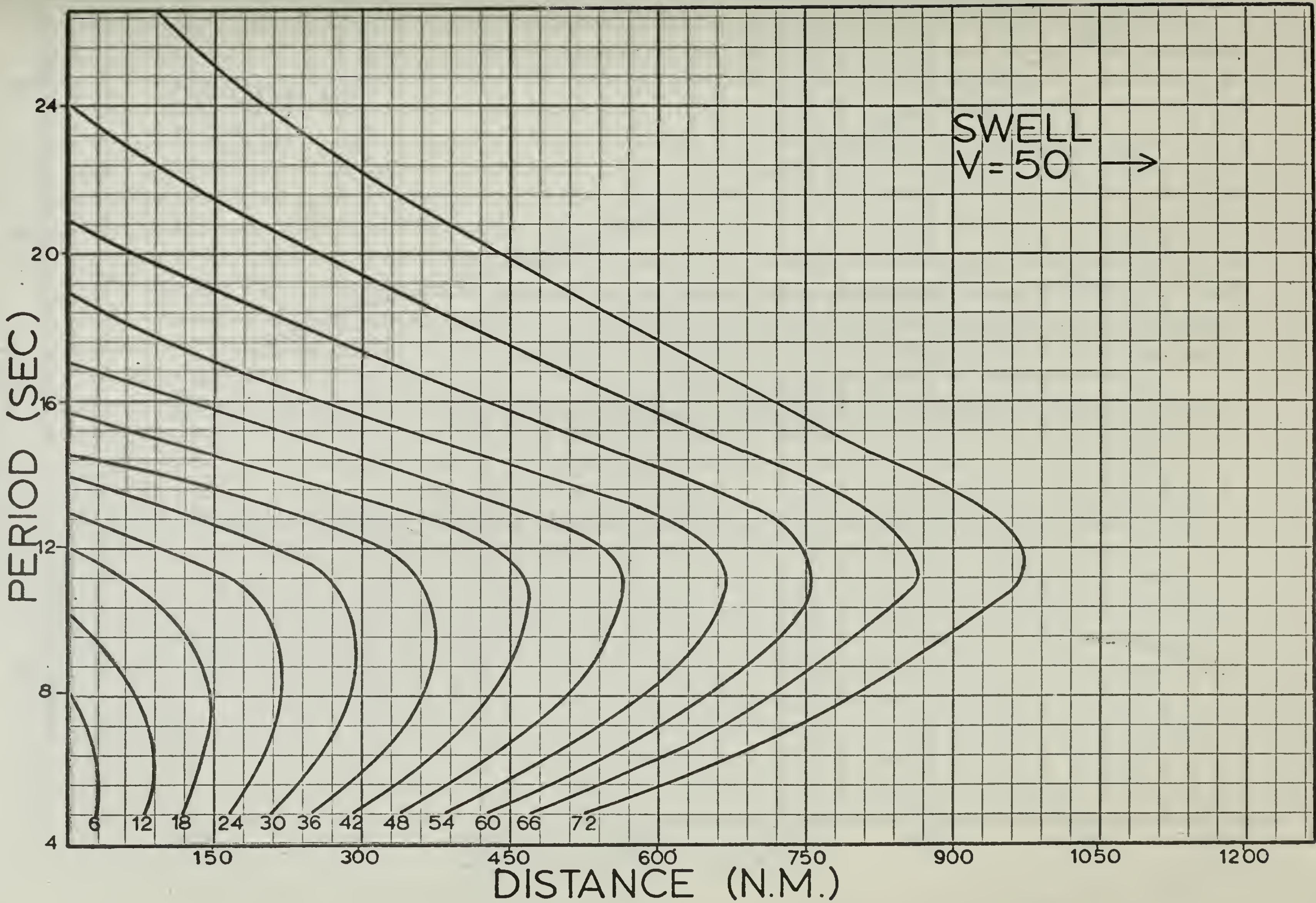

SWELL
V=40 →
42
48
54
60
66
72
36
30
24
18
12
6
PERIOD (SEC)
20
16
12
8
4
0
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)

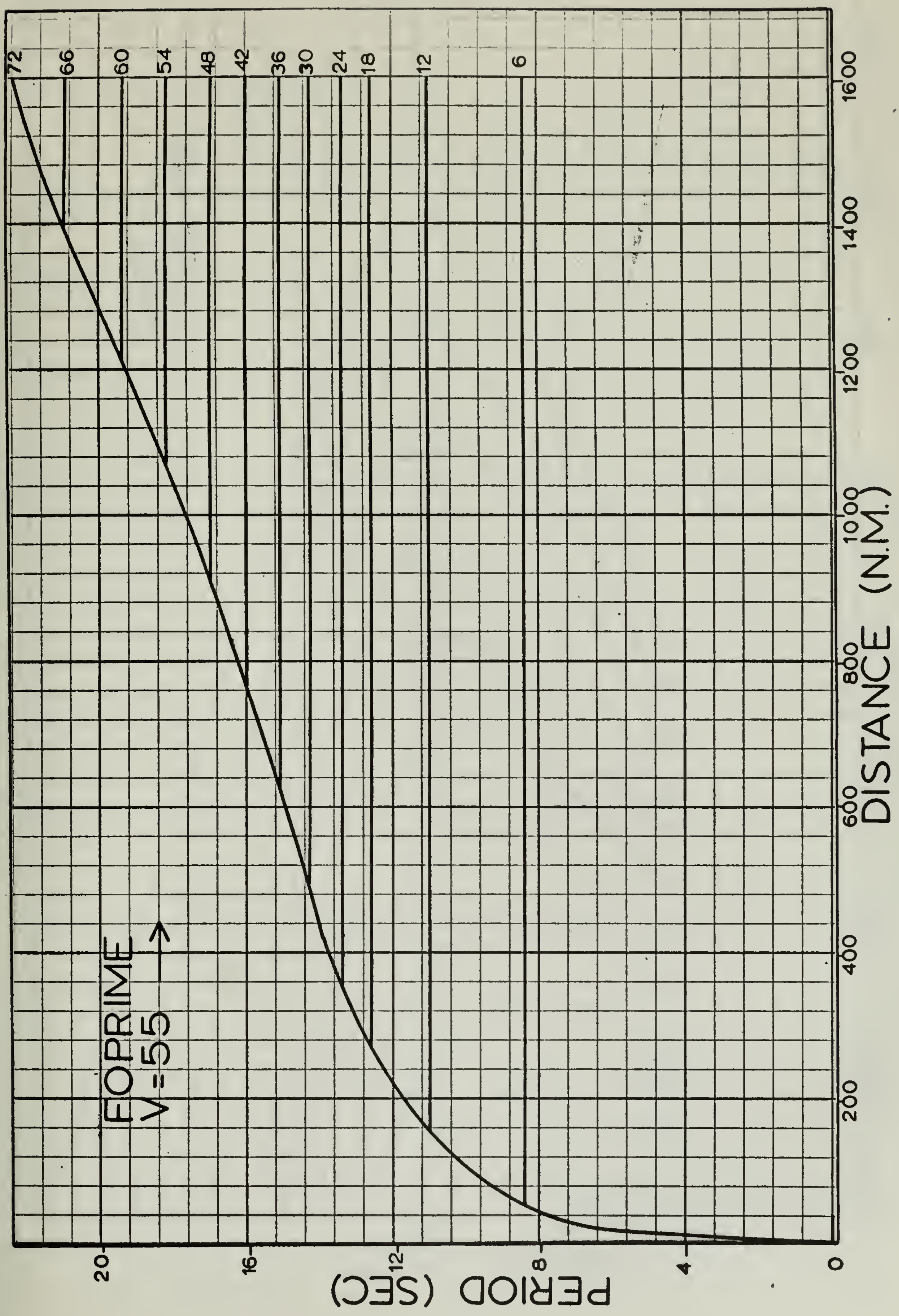

FOPRIME
V= 45 →
54& >
48
42
36
30
24
18
12
6
24
20
16
12
8
4
PERIOD (SEC)
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)

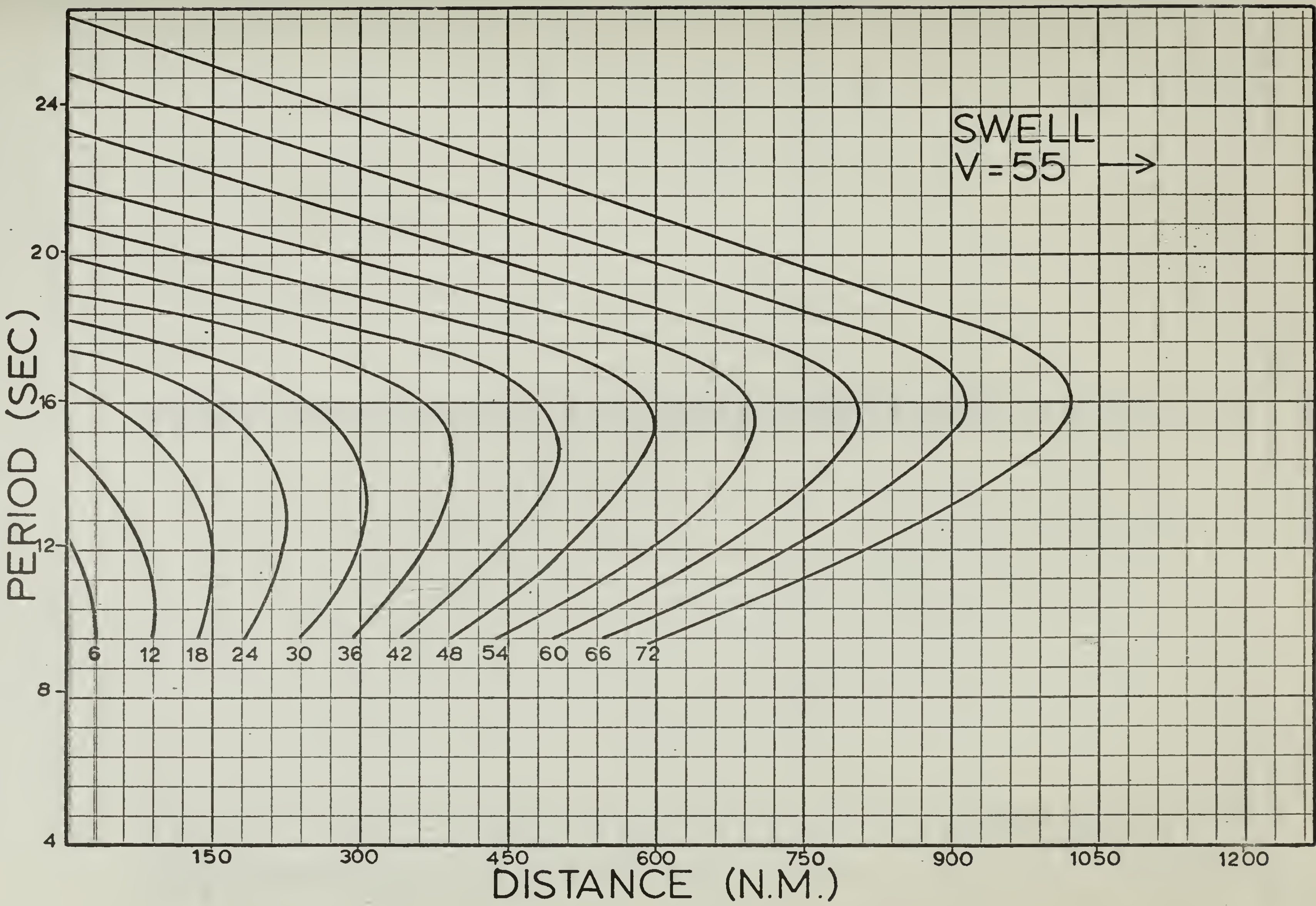


SWELL
V = 45
DISTANCE (N.M.)
PERIOD (SEC)
150
300
450
600
750
900
1050
1200
24
20
16
12
8
4
6
12
18
24
30
36
42
48
54
60
66
72


FOPRIME
V=50 →
PERIOD (SEC)
DISTANCE (N.M.)
4
8
12
16
20
24
200
400
600
800
1000
1200
1400
1600
6
12
18
24
30
36
42
48
54
60
66
72

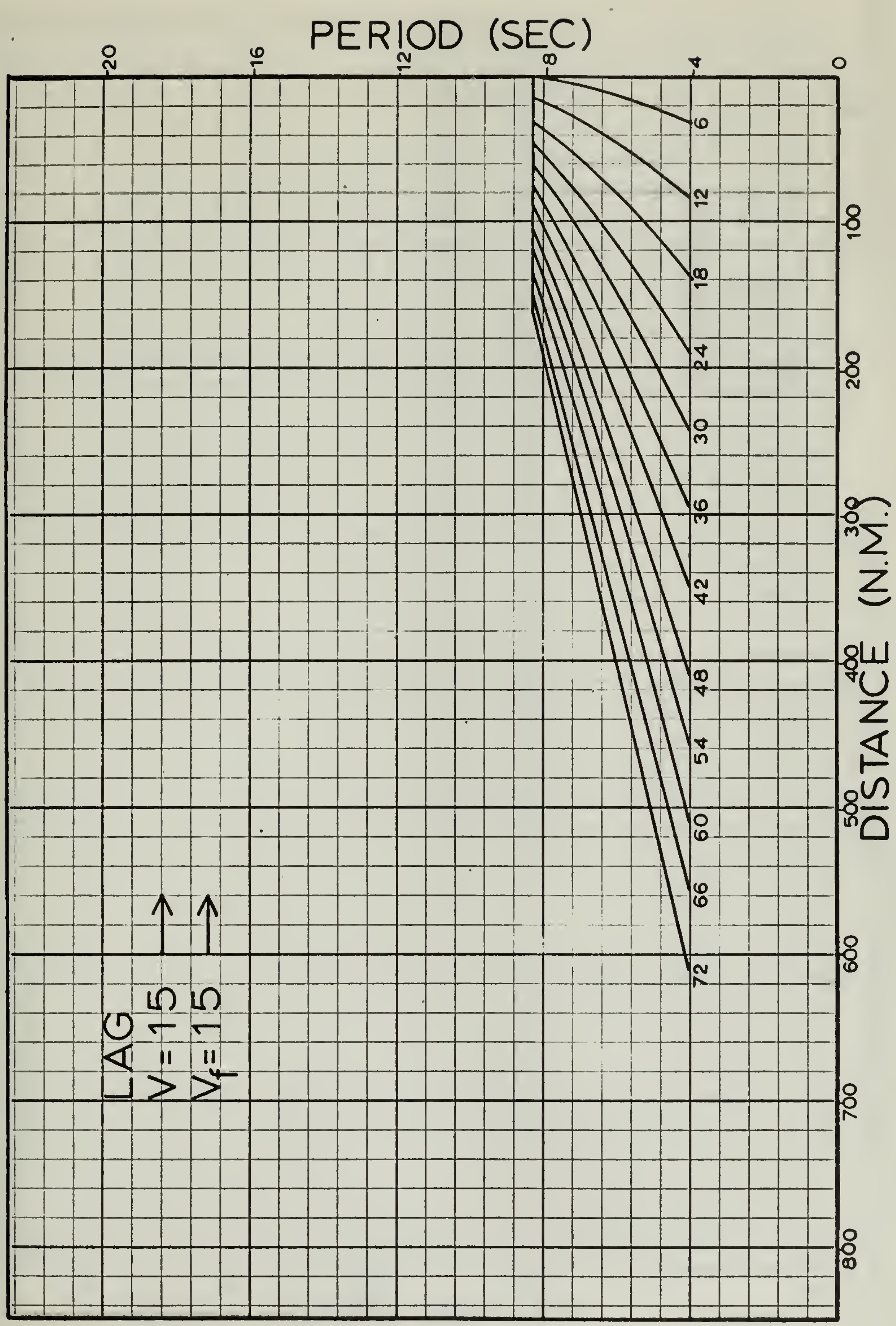

SWELL
V=50 →
PERIOD (SEC)
24
20
16
12
8
4
6
12
18
24
30
36
42
48
54
60
66
72
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)


FOPRIME
V=55
72
66
60
54
48
42
36
30
24
18
12
6
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
PERIOD (SEC)
0
4
8
12
16
20

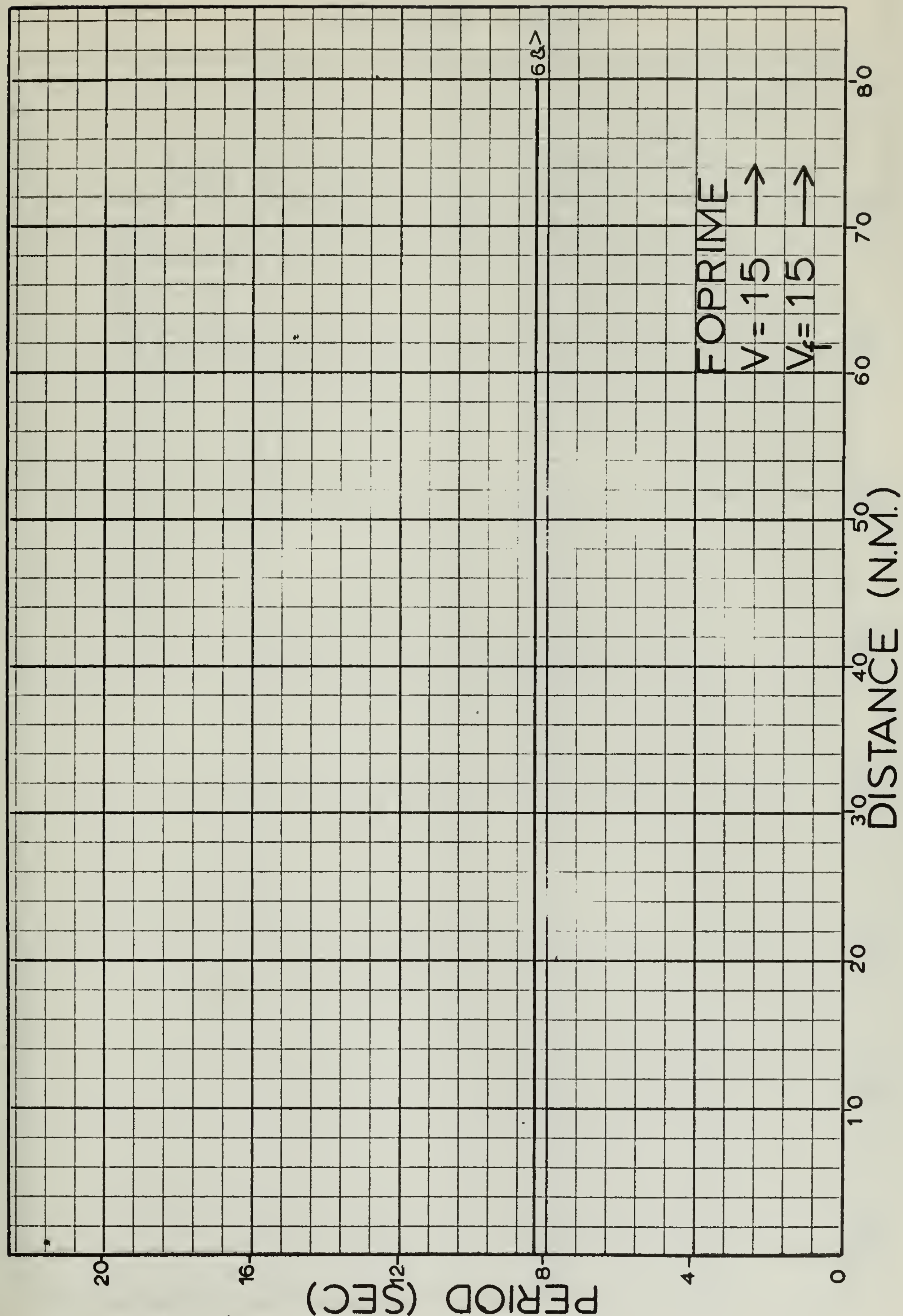

SWELL
V=55
6
12
18
24
30
36
42
48
54
60
66
72
24
20
16
12
8
4
PERIOD (SEC)
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)

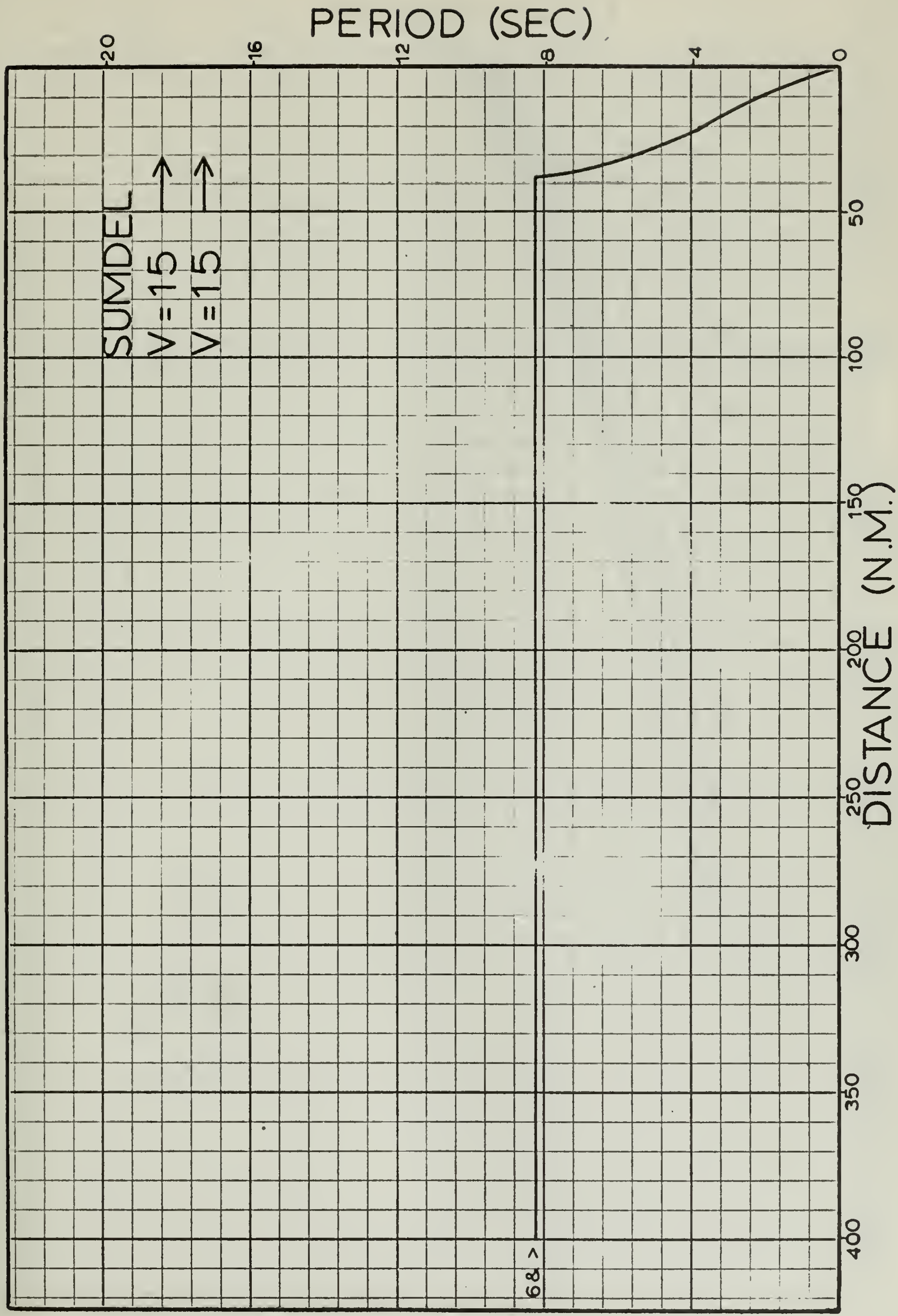
18.2 Moving (leeward) Fetch Model Graphs

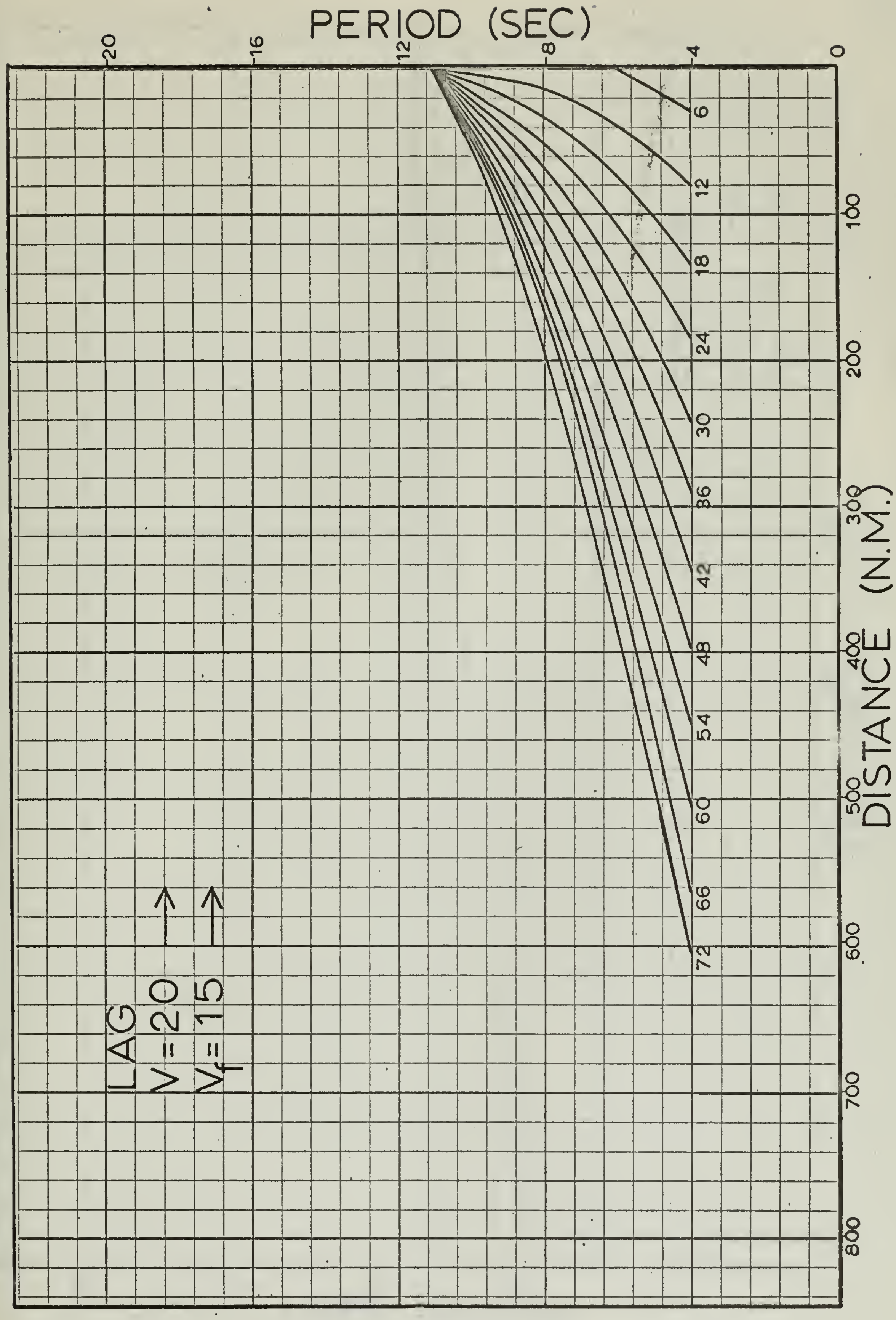
INDEX OF GRAPHS

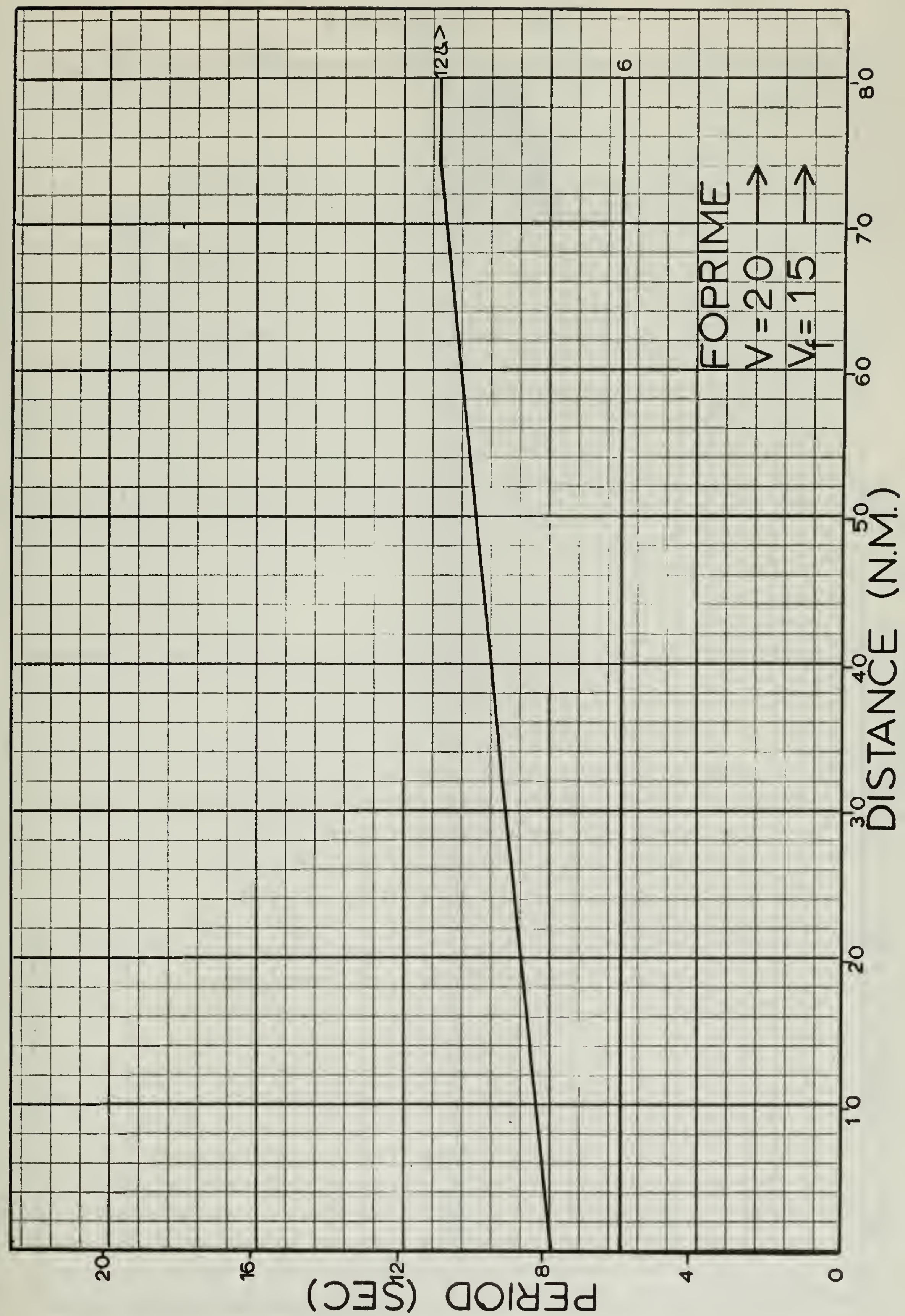


PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
100
200
300
400
500
600
700
800
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 15
V_f = 15

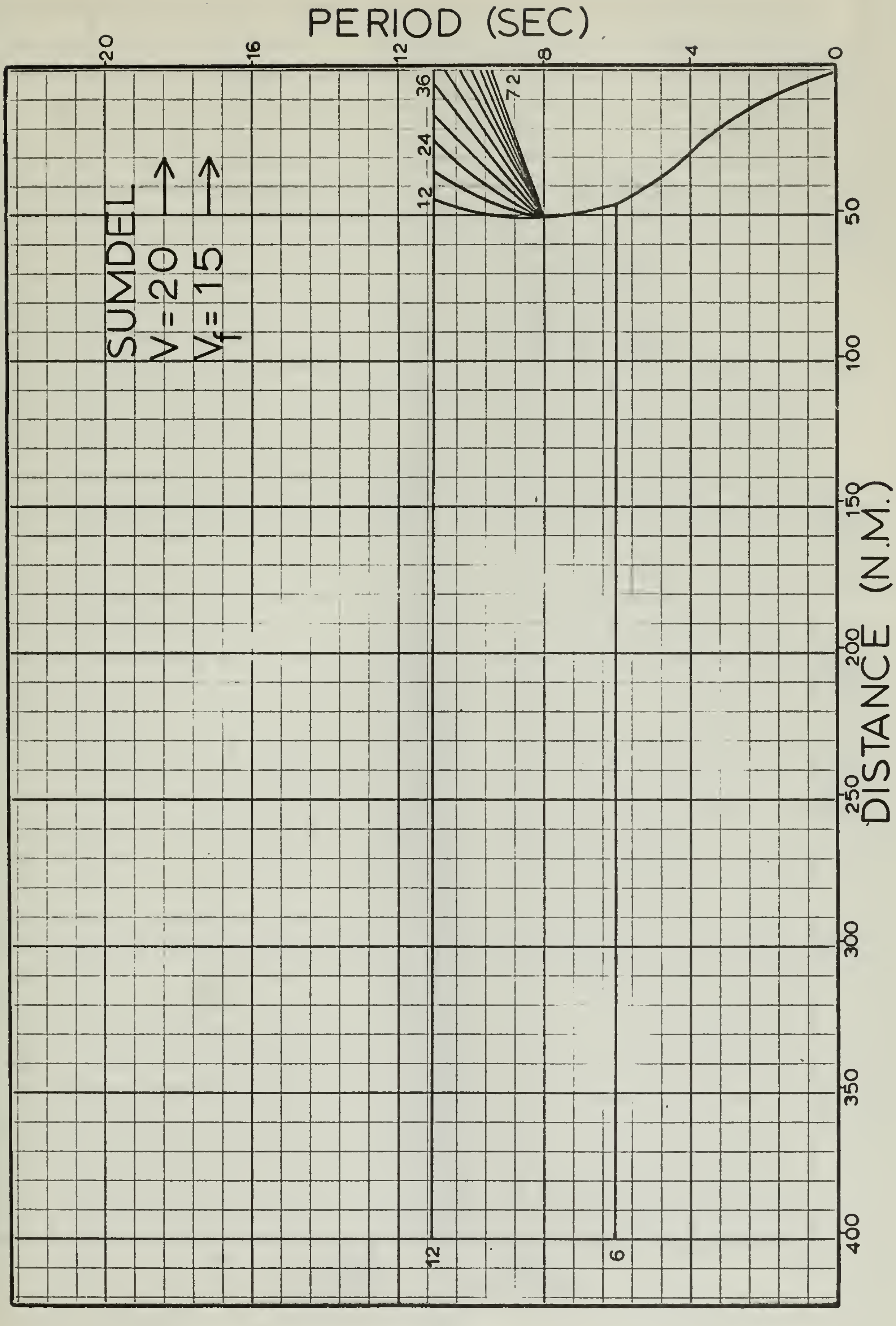

PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
10
20
30
40
50
60
70
80
FOPRIME
V = 15
V_f = 15

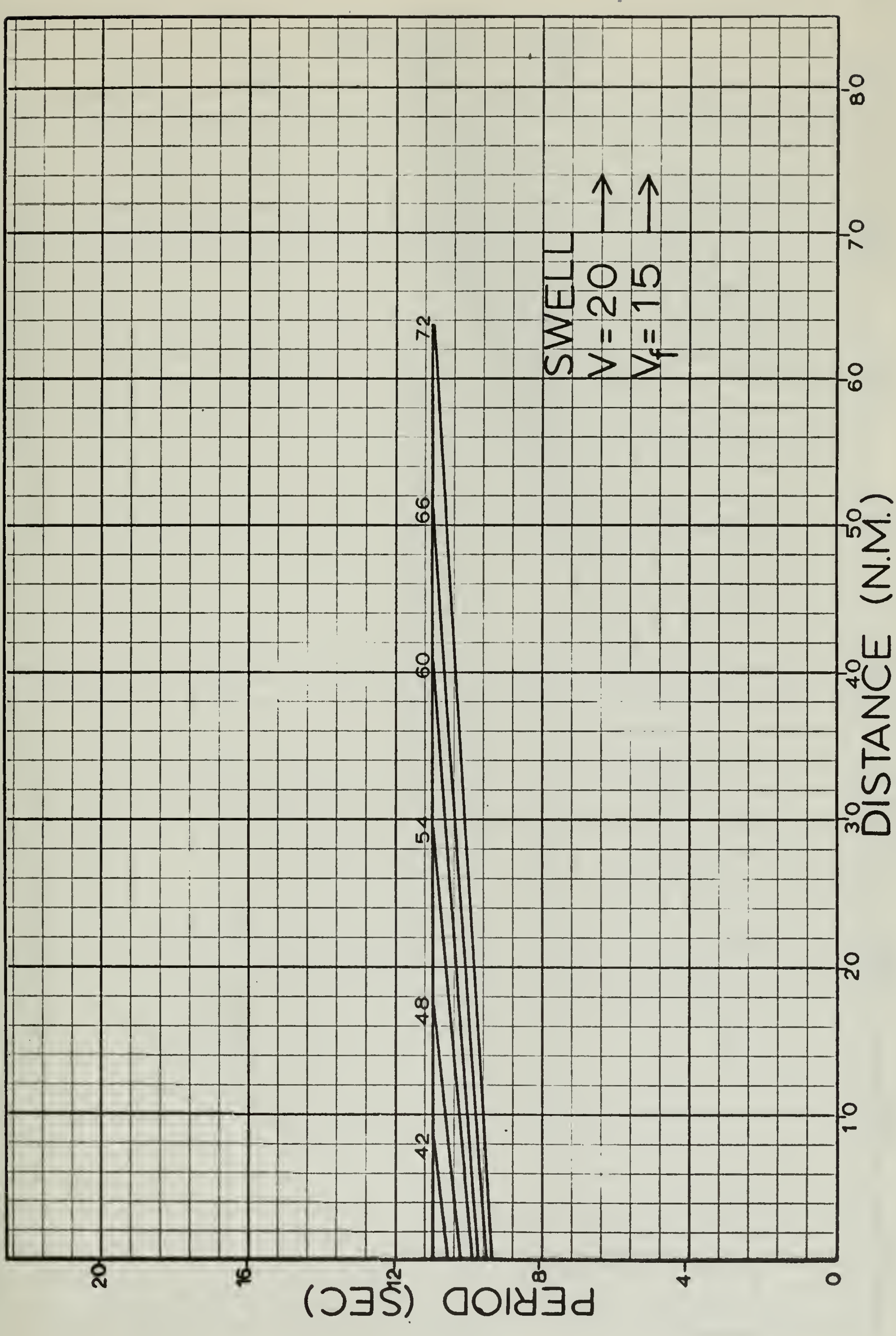

PERIOD (SEC)
20
16
12
8
4
0
SUMDEL
V = 15
V = 15
68 >
50
100
150
200
250
300
350
400
DISTANCE (N.M.)


PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
100
200
300
400
500
600
700
800
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 20
V_f = 15

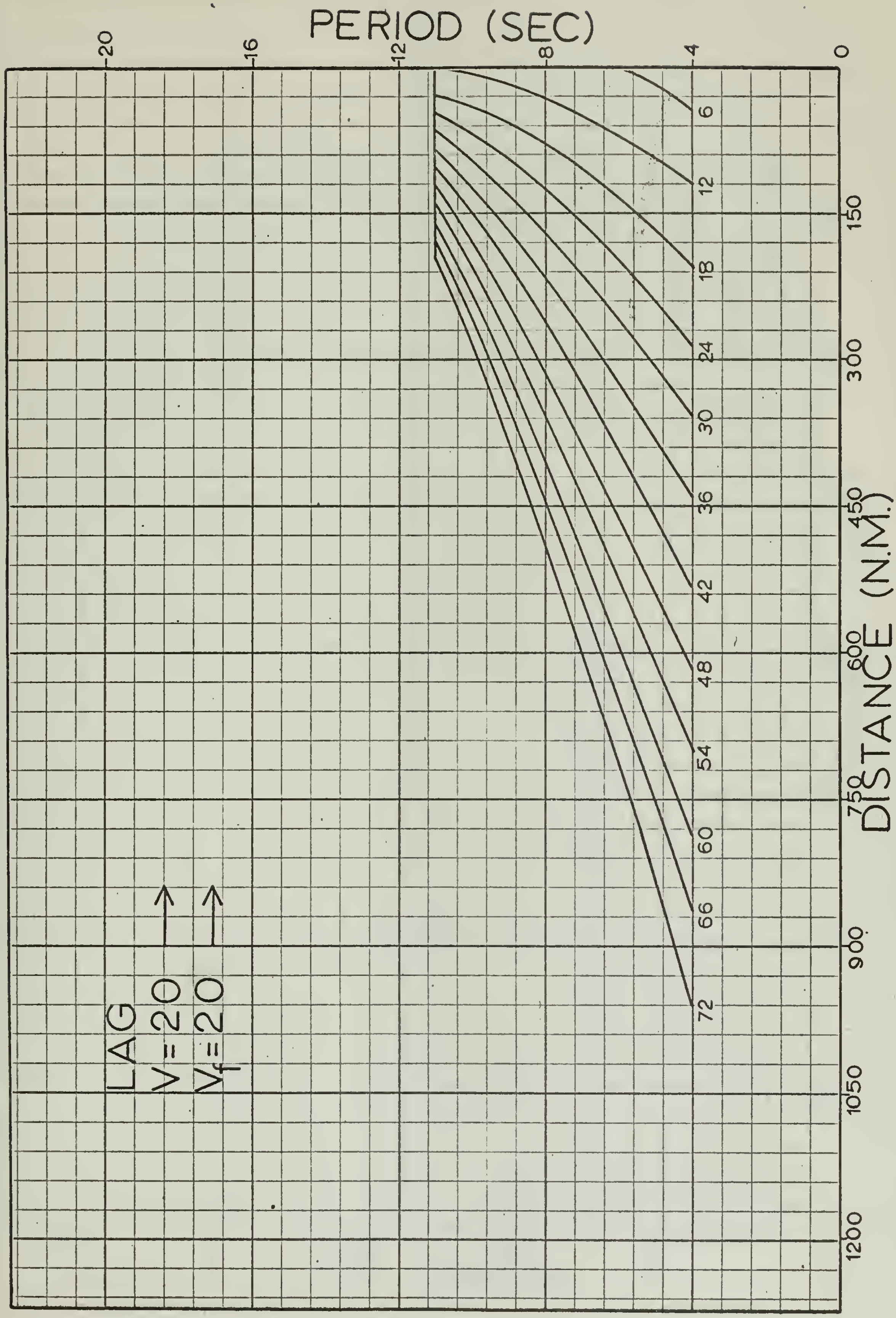


PERIOD (SEC)
DISTANCE (N.M.)
FOPRIME
V = 20
$V_f$ = 15
12&>
6
0
4
8
12
16
20
10
20
30
40
50
60
70
80

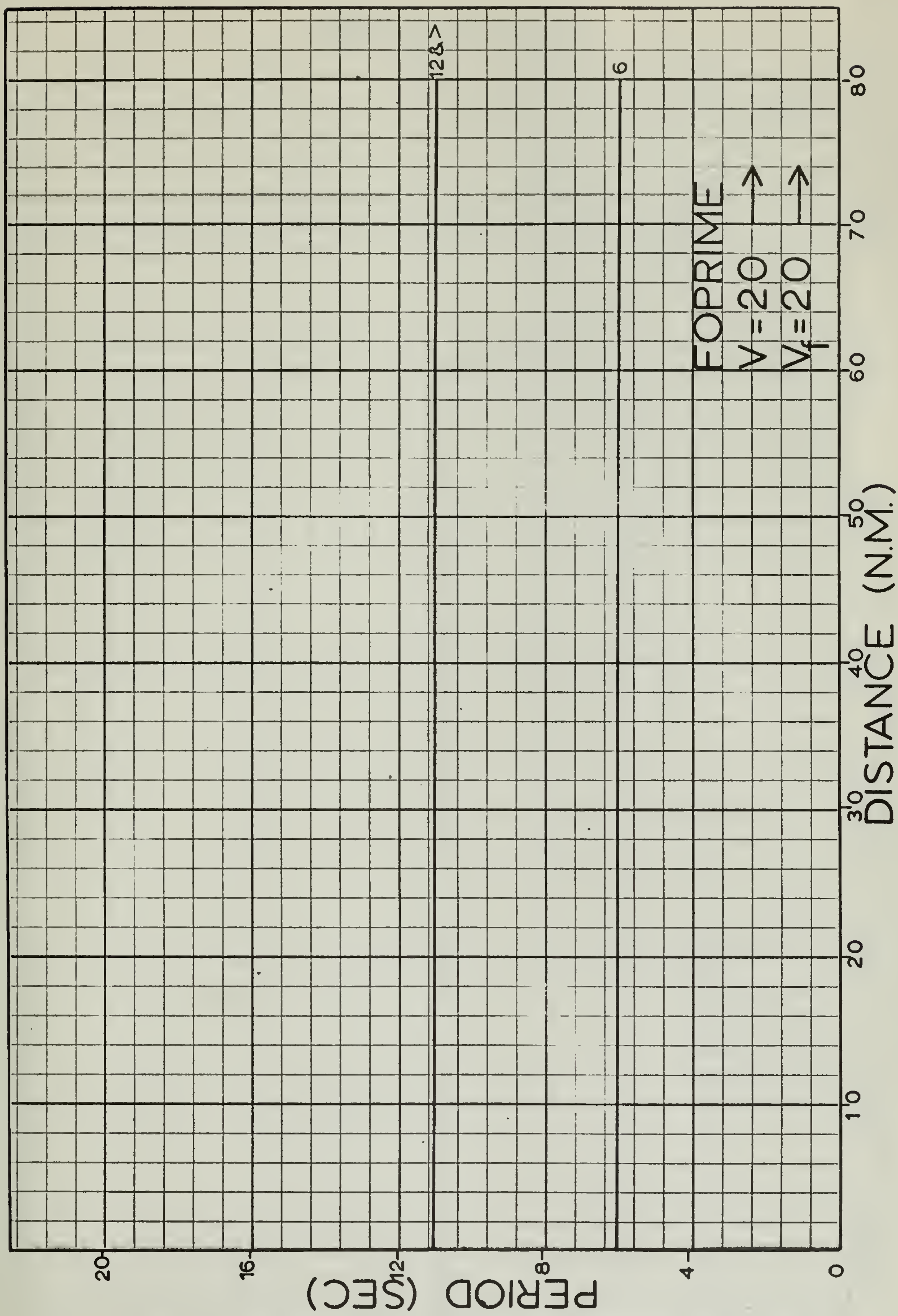

PERIOD (SEC)
20
16
12
8
4
0
SUMDEL
V = 20
Vf = 15
12
24
36
72
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
12
6

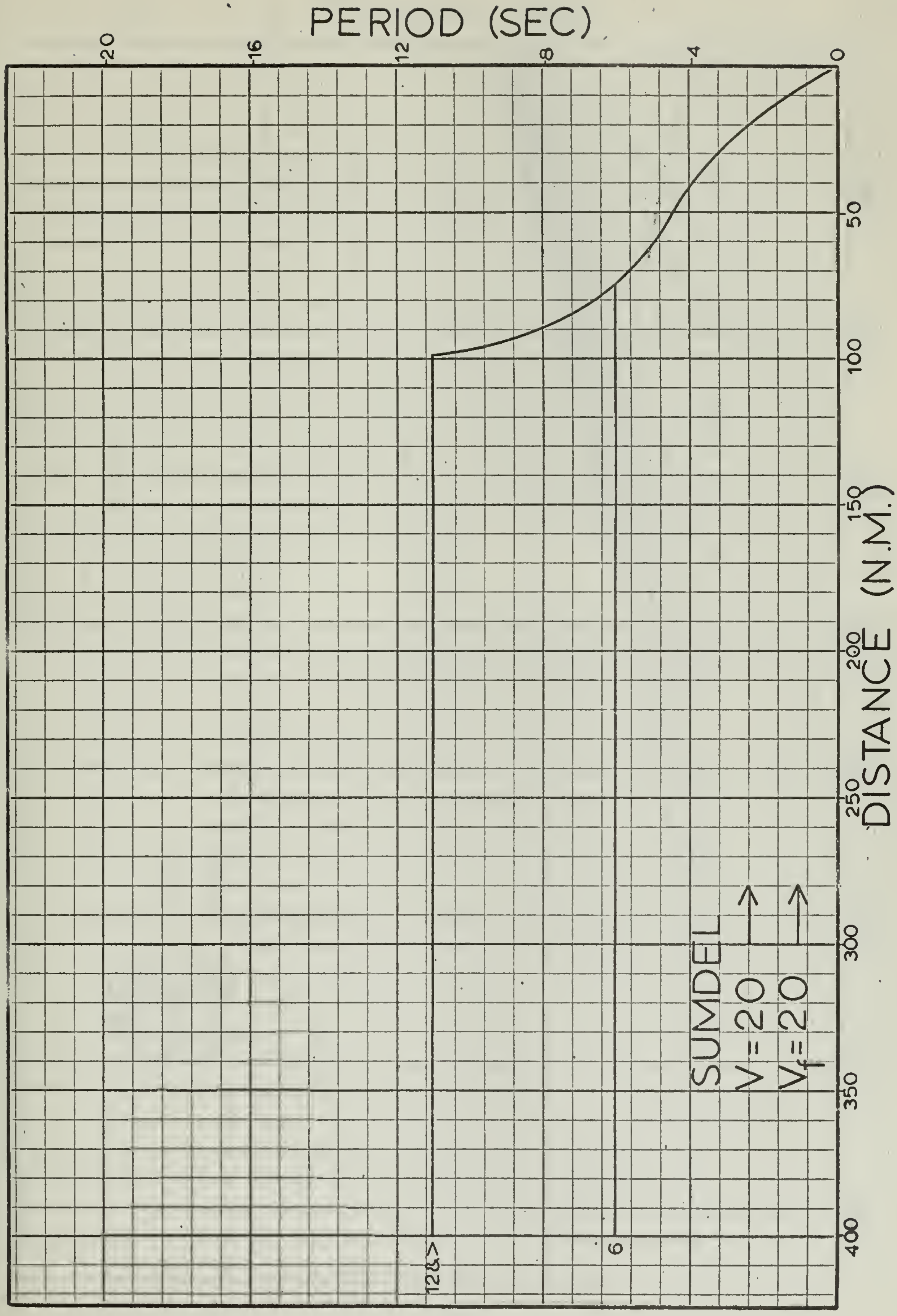


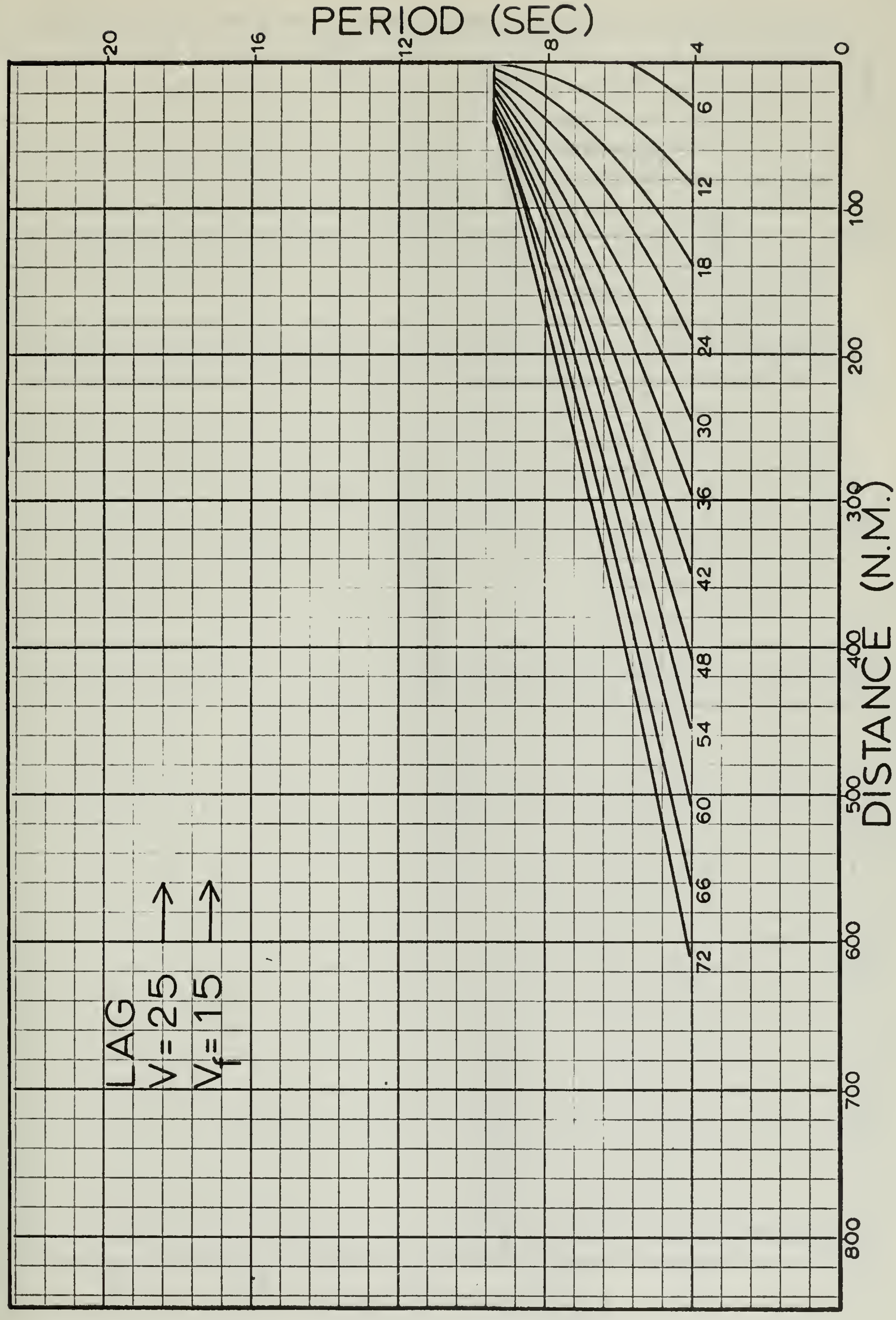
SWELL
V = 20
$V_f$ = 15
42
48
54
60
66
72
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
10
20
30
40
50
60
70
80



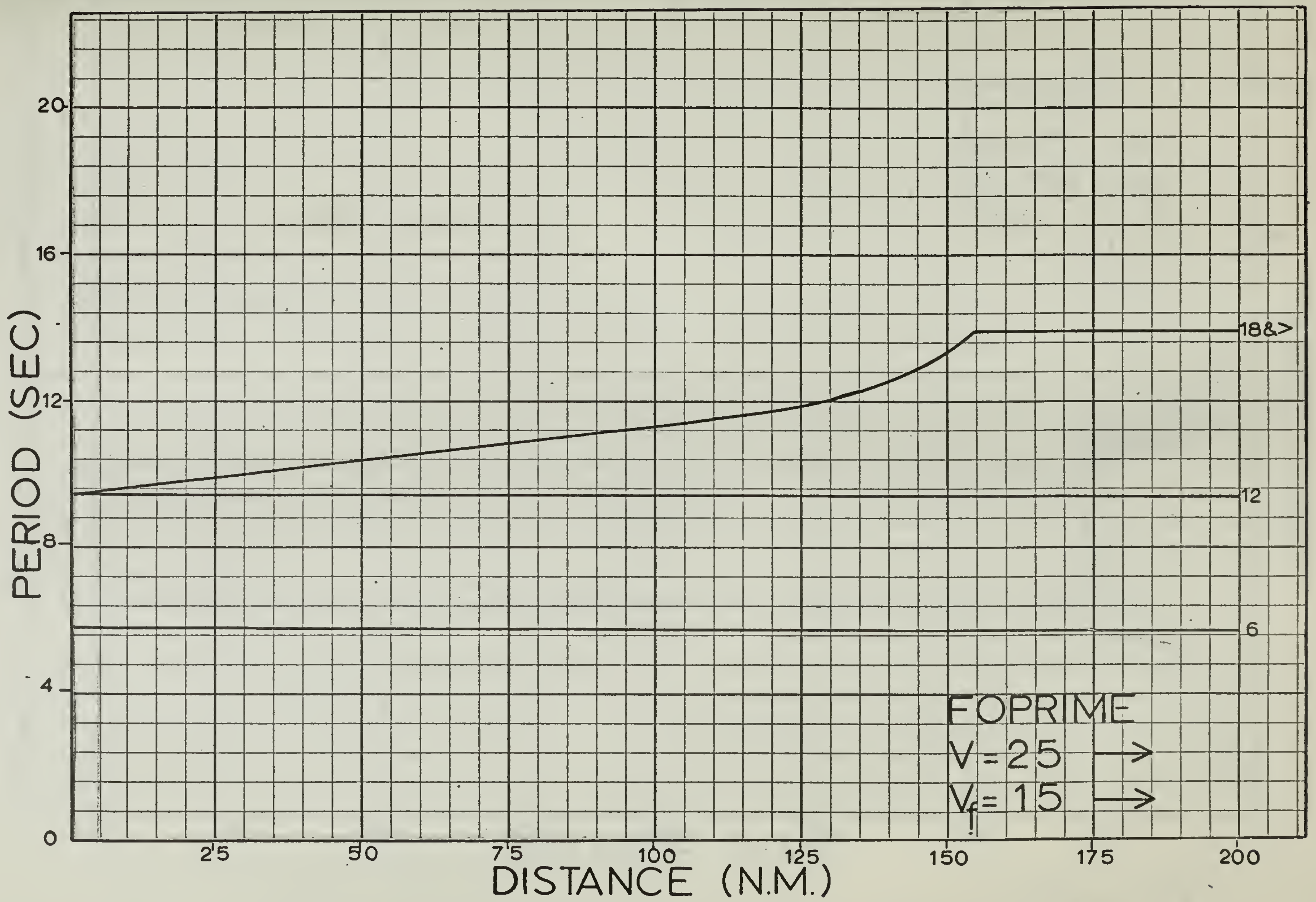
PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
150
300
450
600
750
900
1050
1200
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 20
V_f = 20


FOPRIME
V = 20
Vf = 20
12&>
6
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
10
20
30
40
50
60
70
80

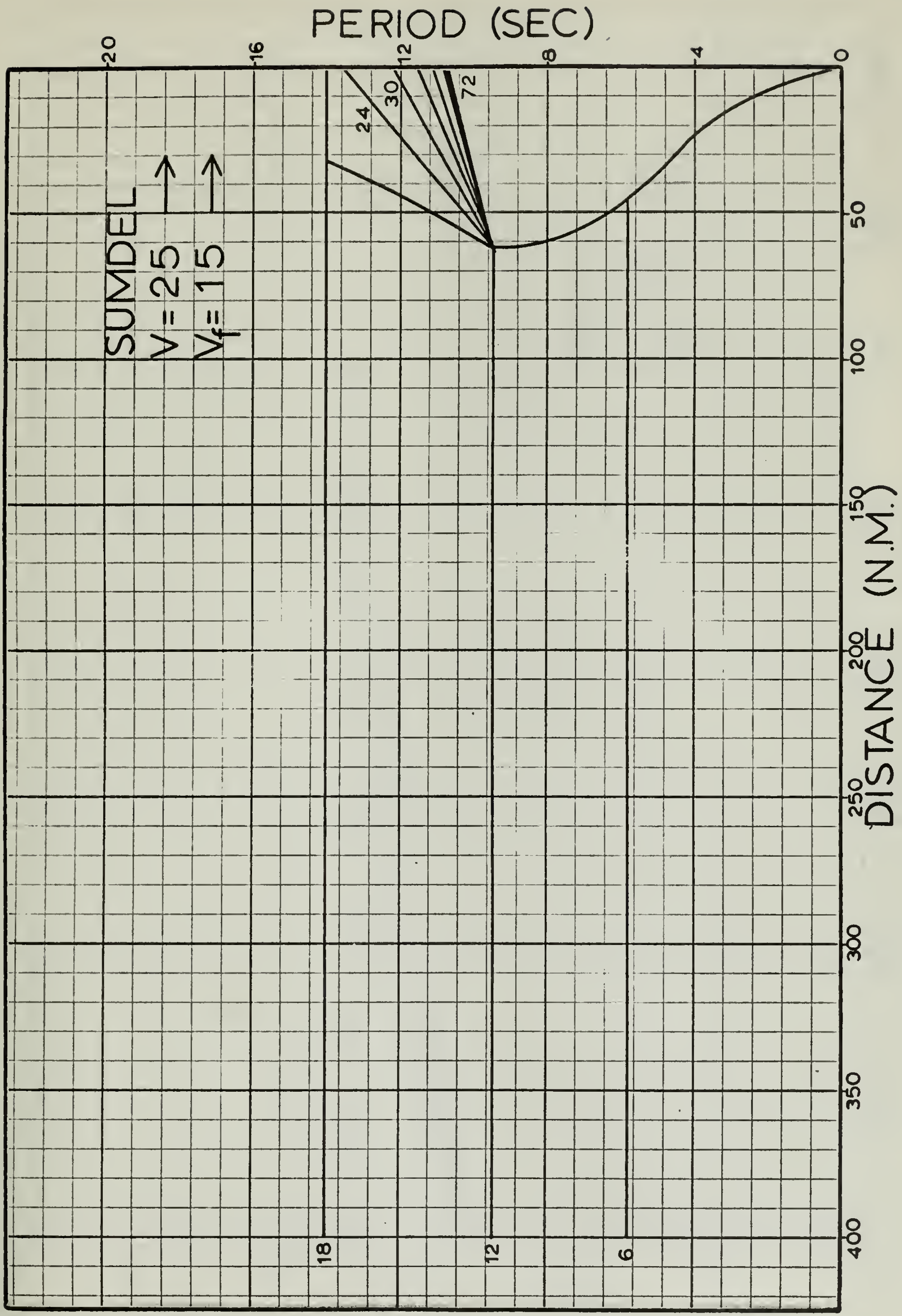

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
50
100
150
200
250
300
350
400
SUMDEL
V = 20
V_f = 20
12 & >
6

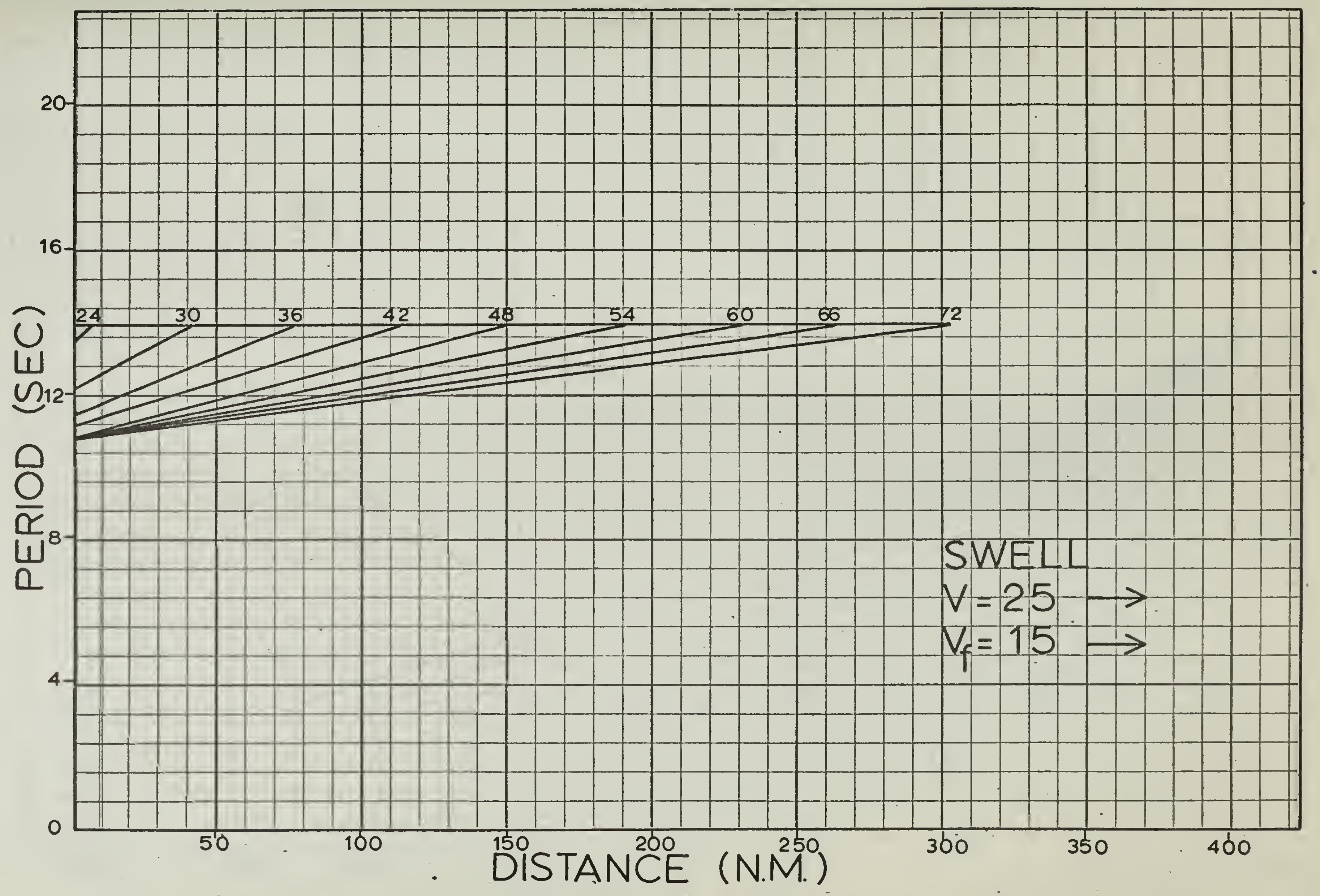


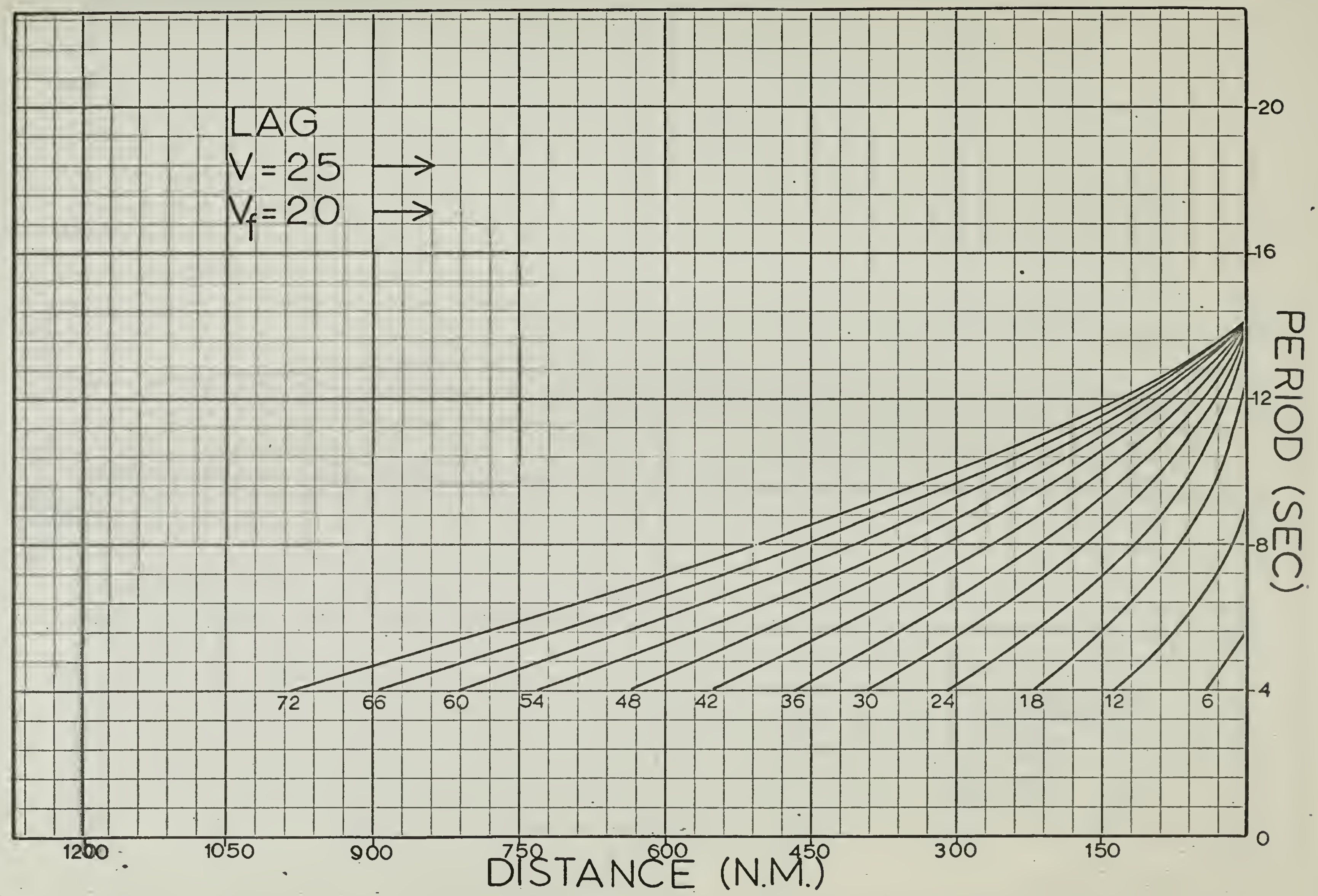
PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
100
200
300
400
500
600
700
800
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 25 →
V_f = 15 →



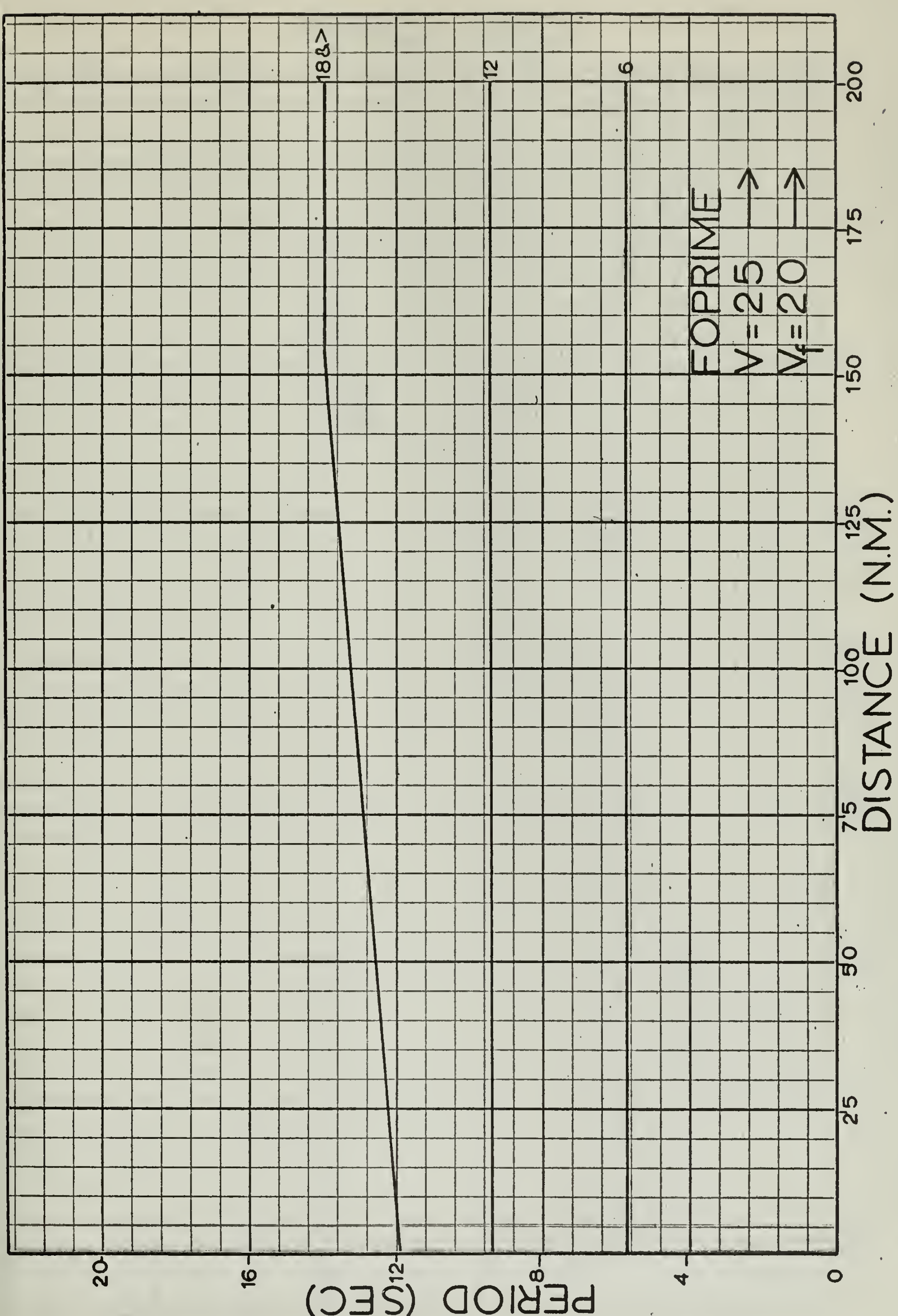
PERIOD (SEC)
20
16
12
8
4
0
25
50
75
100
125
150
175
200
DISTANCE (N.M.)
18&>
12
6
FOPRIME
V = 25
V_f = 15

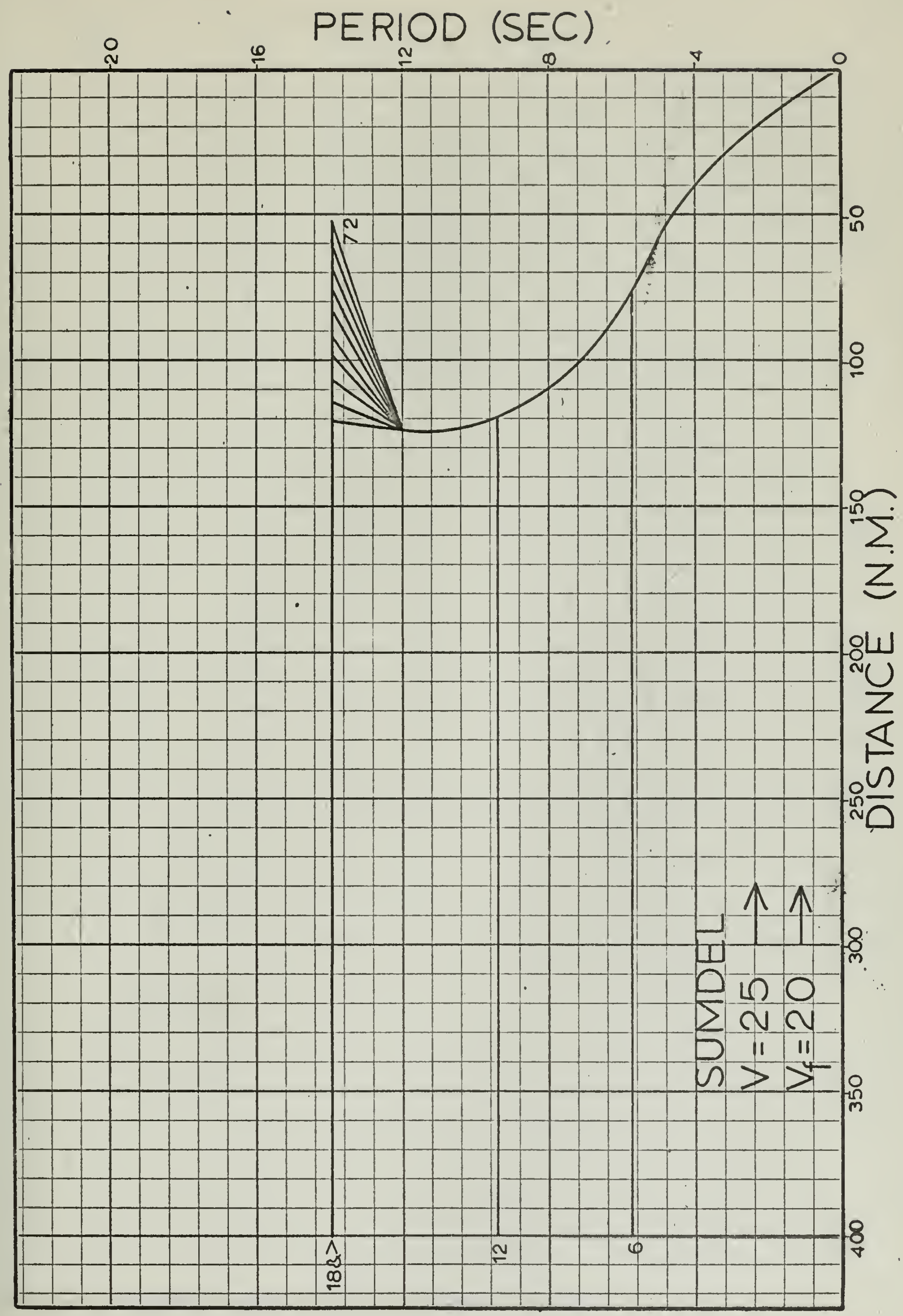

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
50
100
150
200
250
300
350
400
SUMDEL
V = 25
V_f = 15
24
30
72
18
12
6

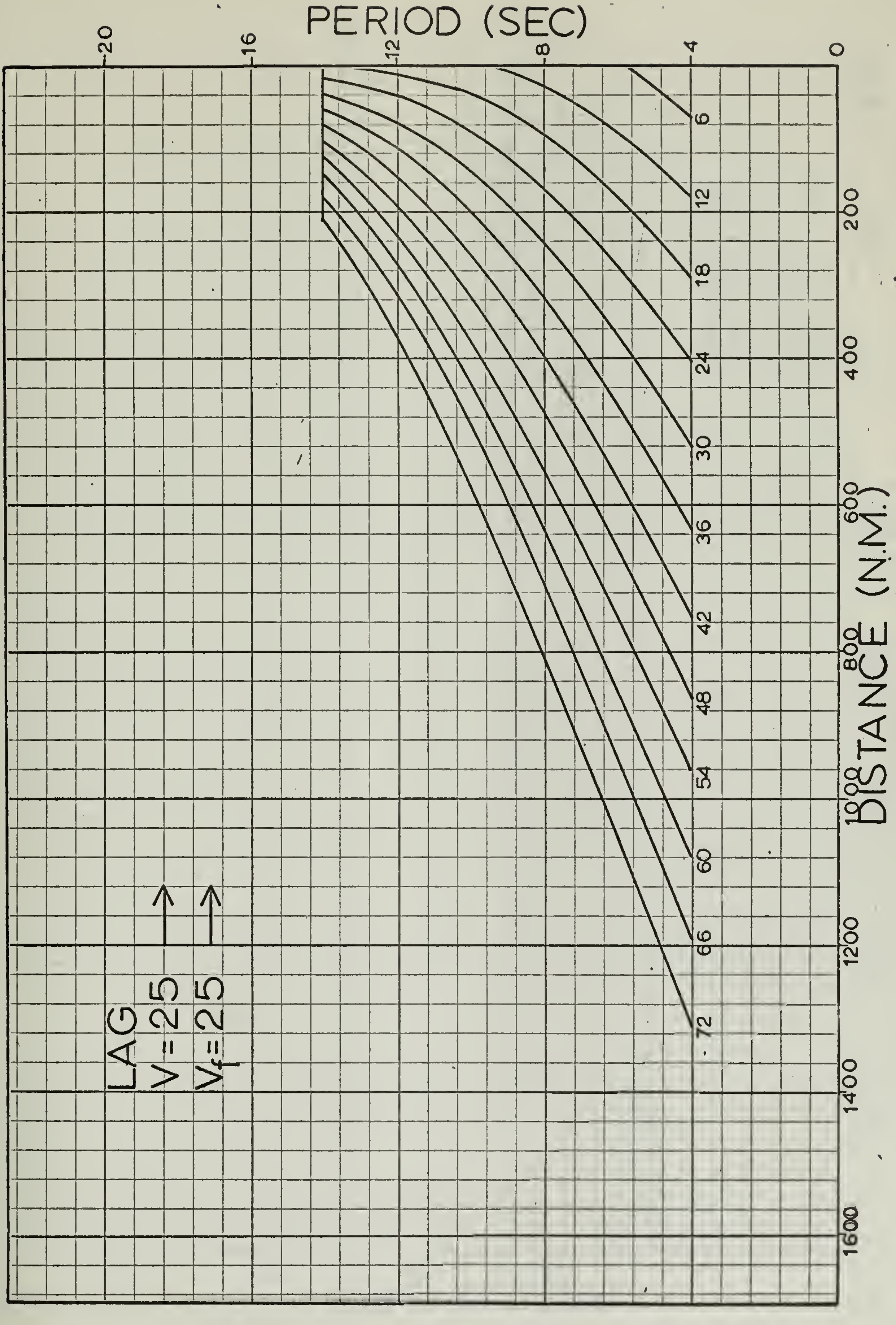

PERIOD (SEC)
20
16
12
8
4
0
24
30
36
42
48
54
60
66
72
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
SWELL
V = 25
$V_f$ = 15

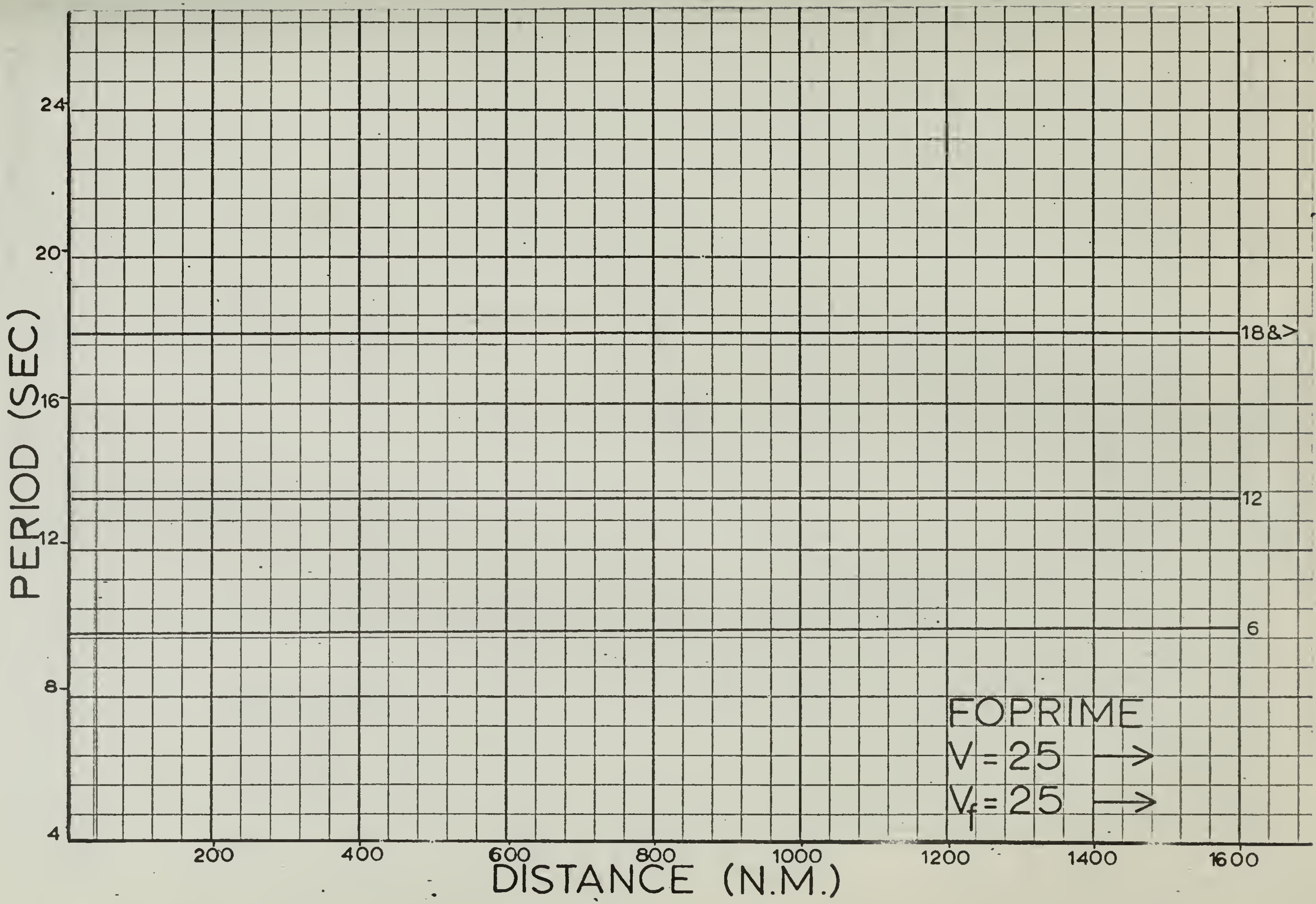


LAG
V = 25
$V_f$ = 20
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
1200
1050
900
750
600
450
300
150
72
66
60
54
48
42
36
30
24
18
12
6

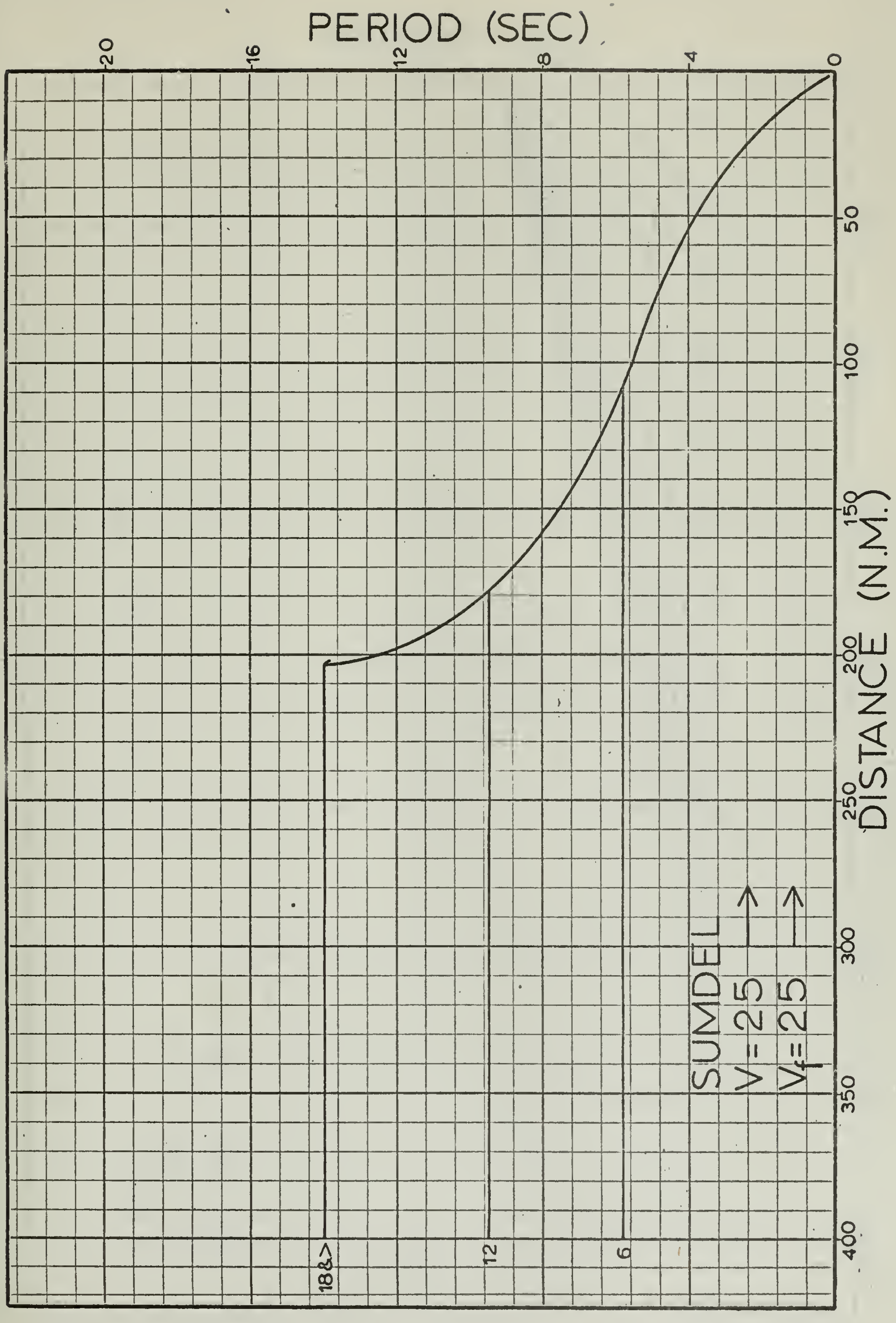

FOPRIME
V = 25
Vf = 20
18&>
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
25
50
75
100
125
150
175
200

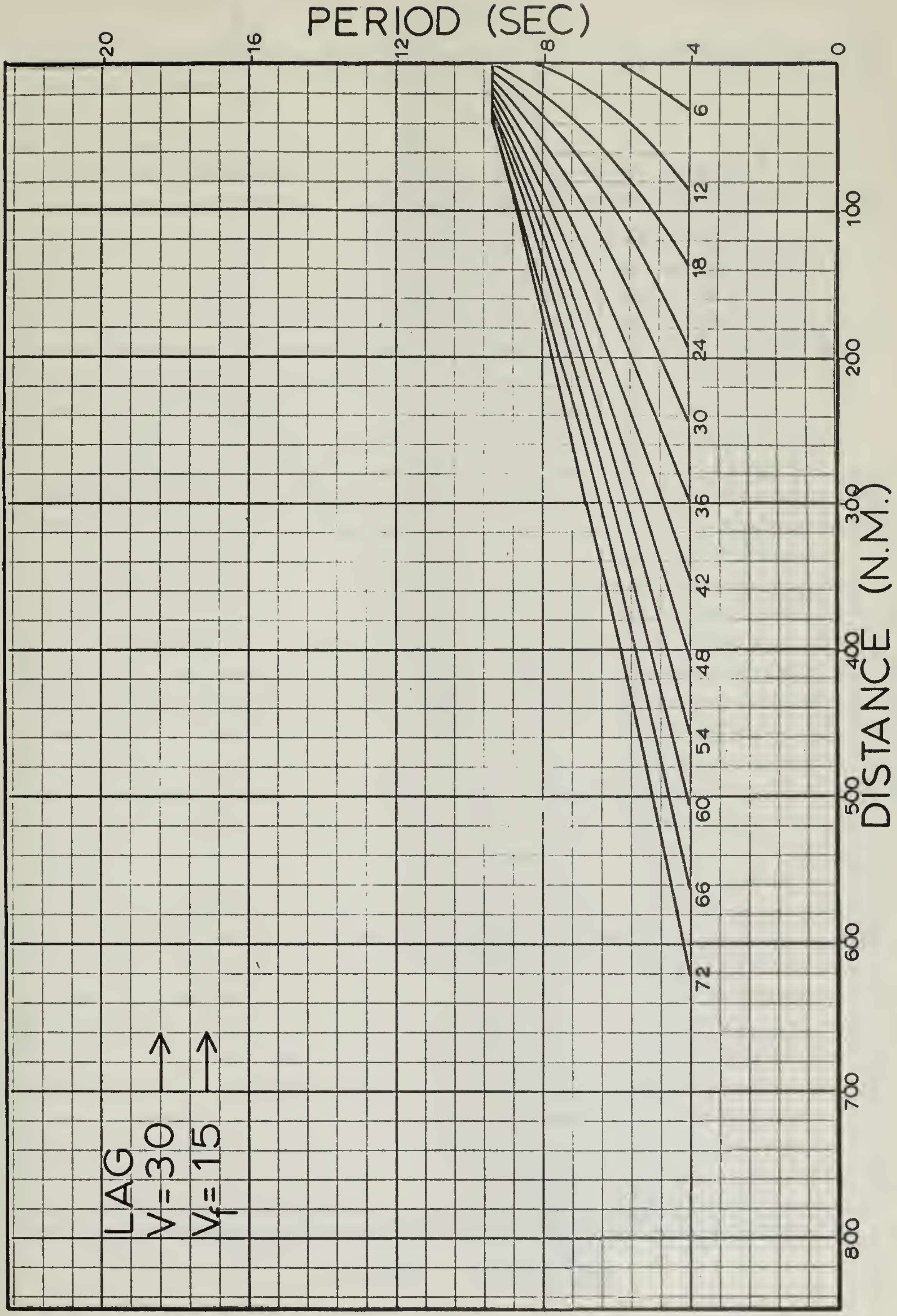

PERIOD (SEC)
20
16
12
8
4
0
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
72
18&>
12
6
SUMDEL
V = 25
V_f = 20

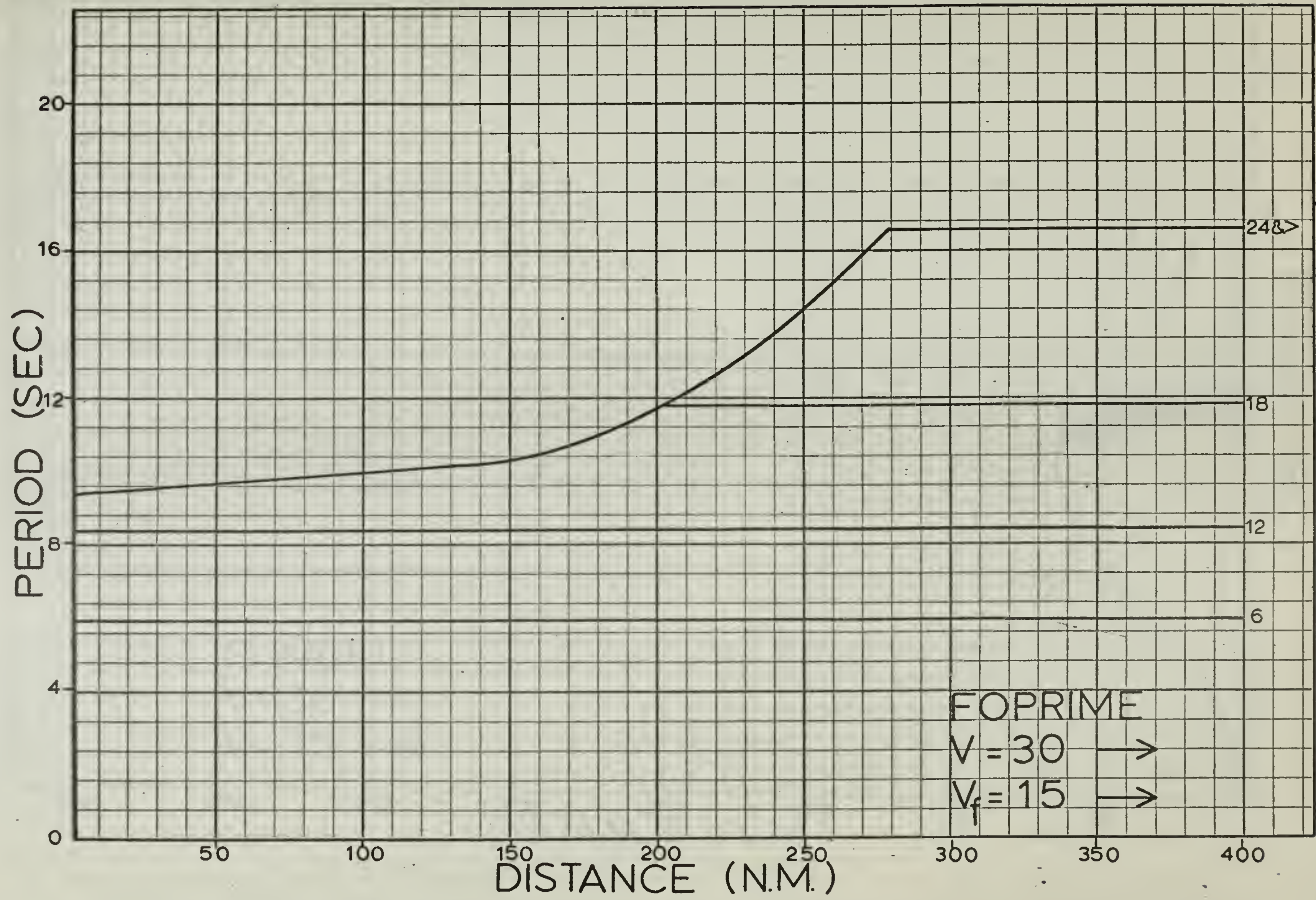

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 25
$V_f$ = 25



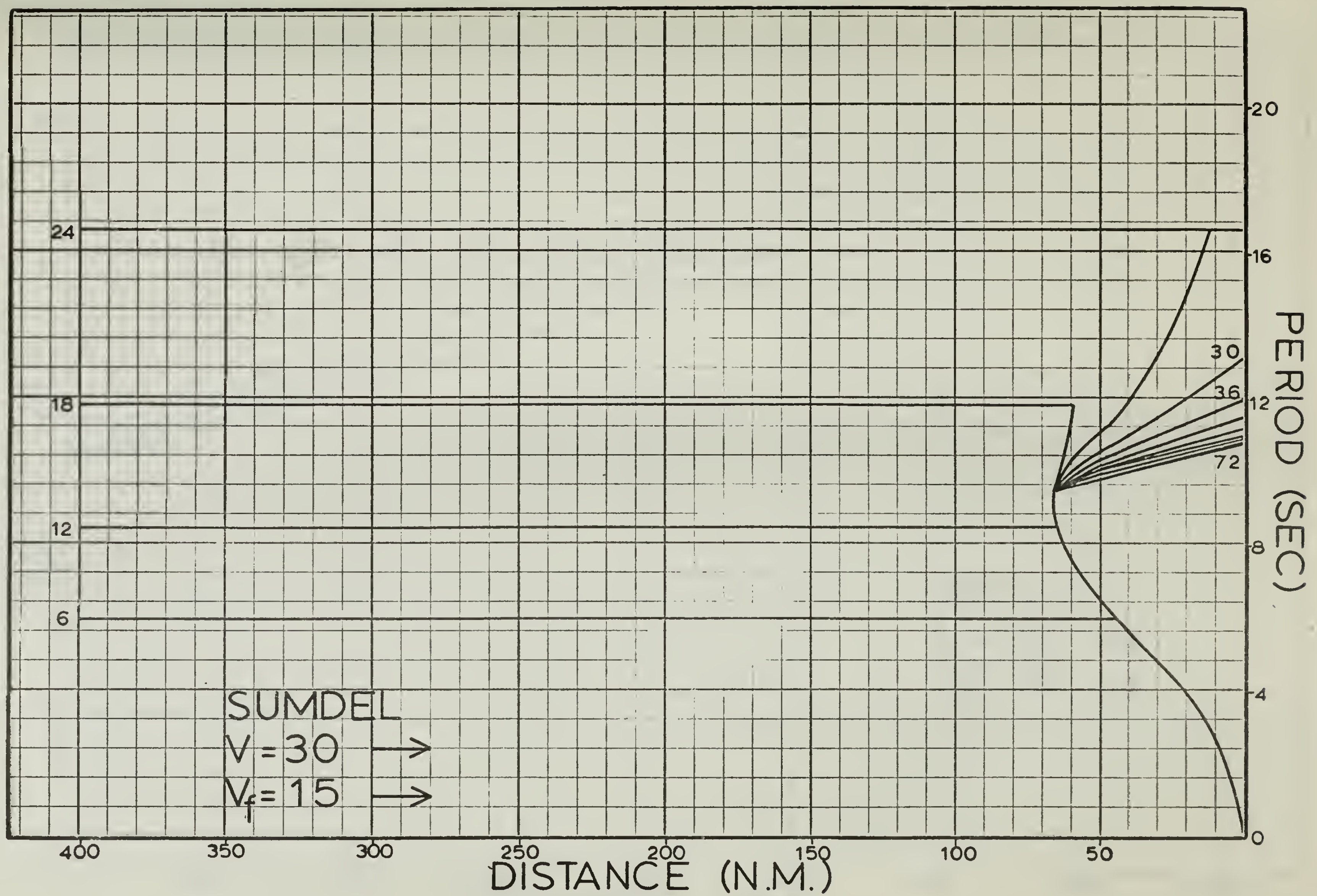
PERIOD (SEC)
24
20
16
12
8
4
18&>
12
6
FOPRIME
V = 25
Vf = 25
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)


PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
50
100
150
200
250
300
350
400
SUMDEL
V = 25
$V_f$ = 25
18&>
12
6

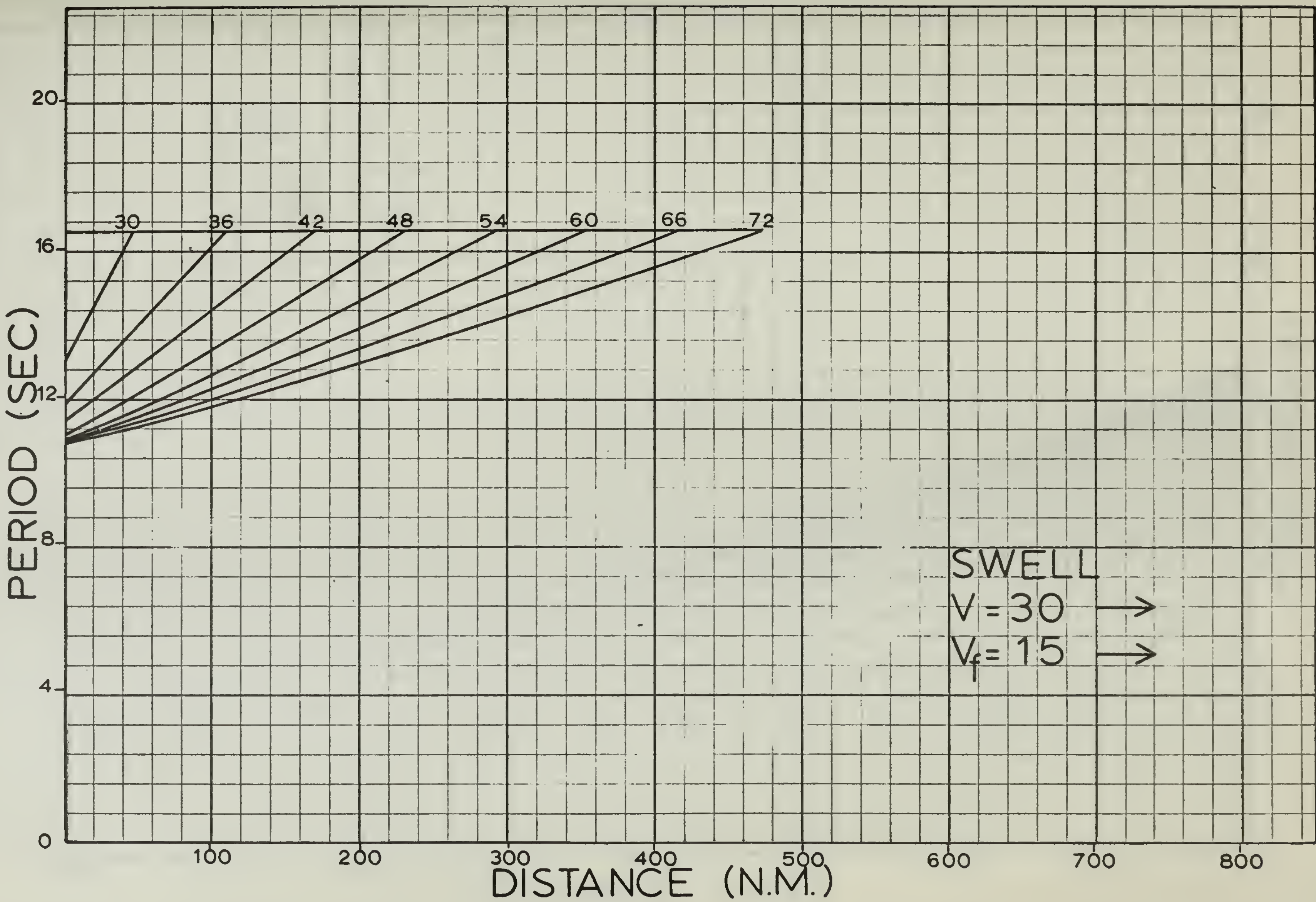

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
100
200
300
400
500
600
700
800
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 30 →
$V_f$ = 15 →

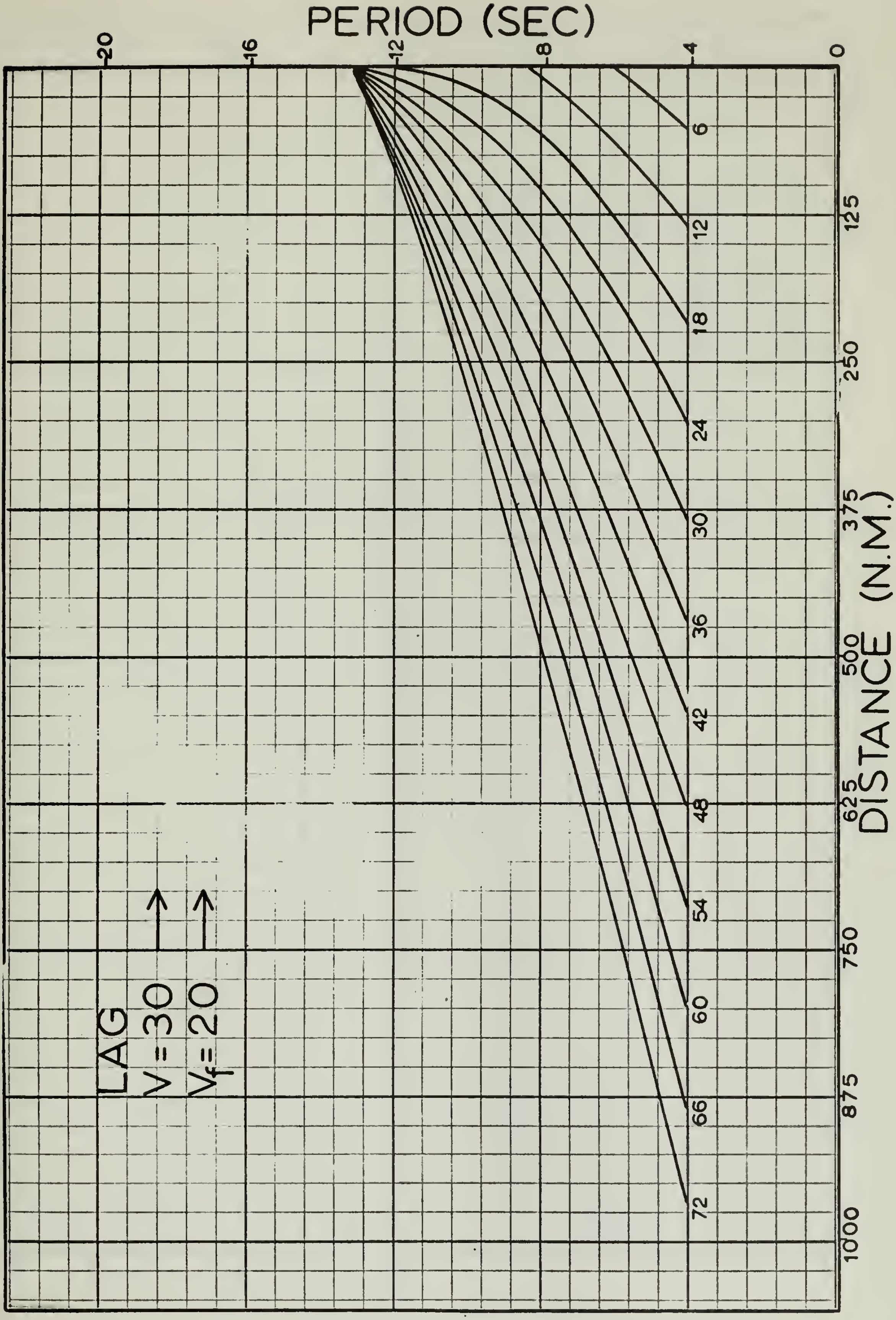


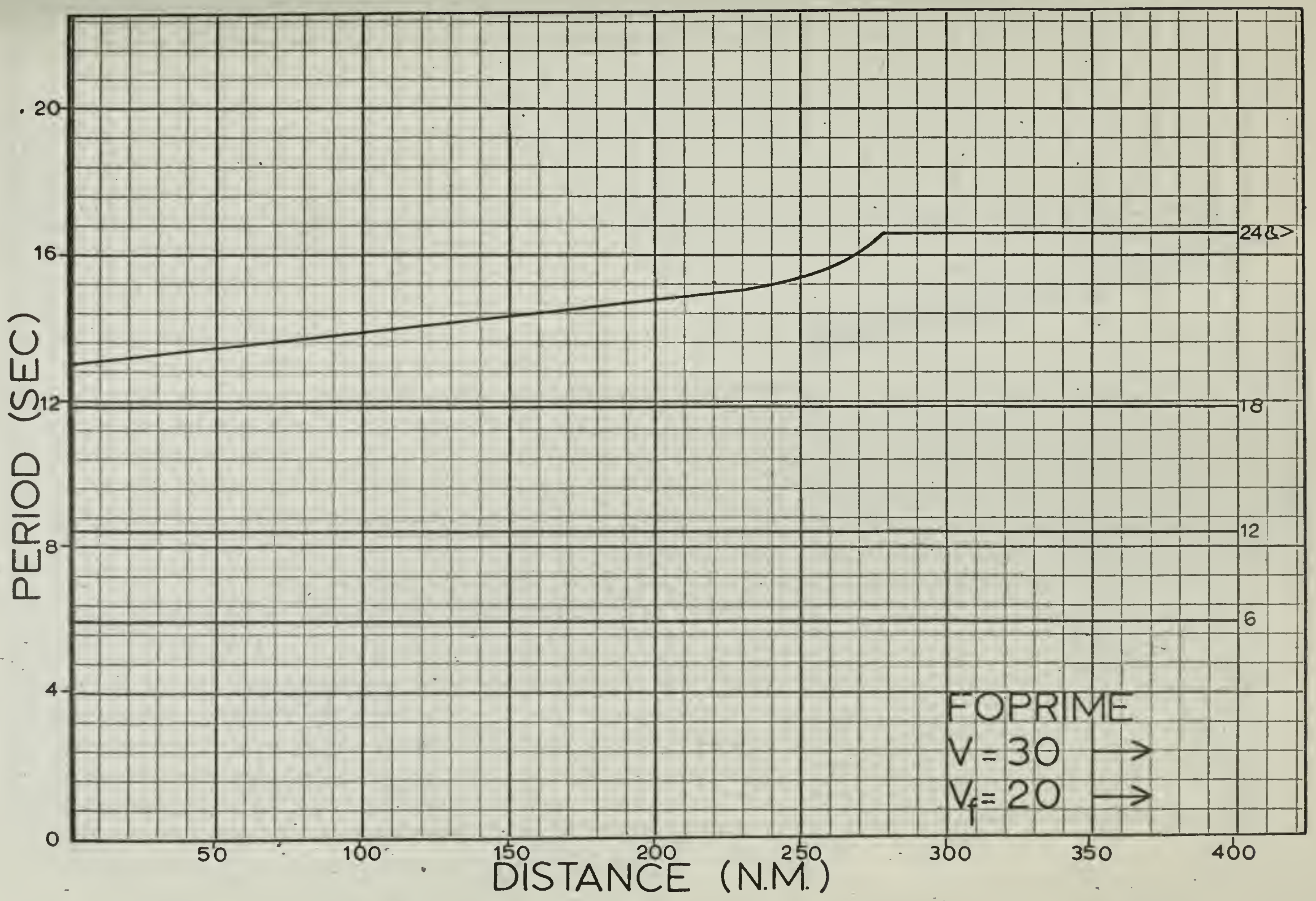
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
50
100
150
200
250
300
350
400
24&>
18
12
6
FOPRIME
$V = 30$ →
$V_f = 15$ →

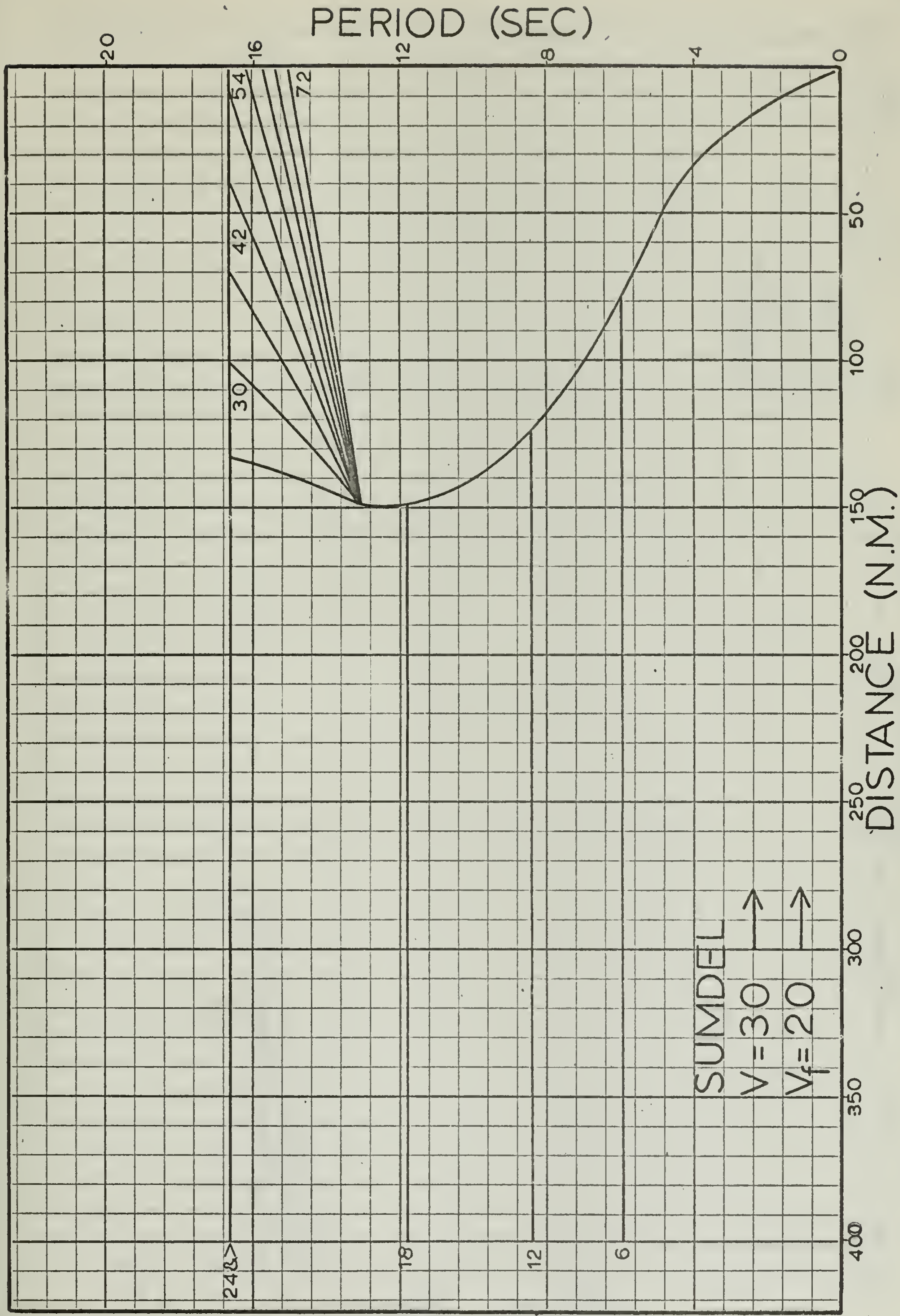


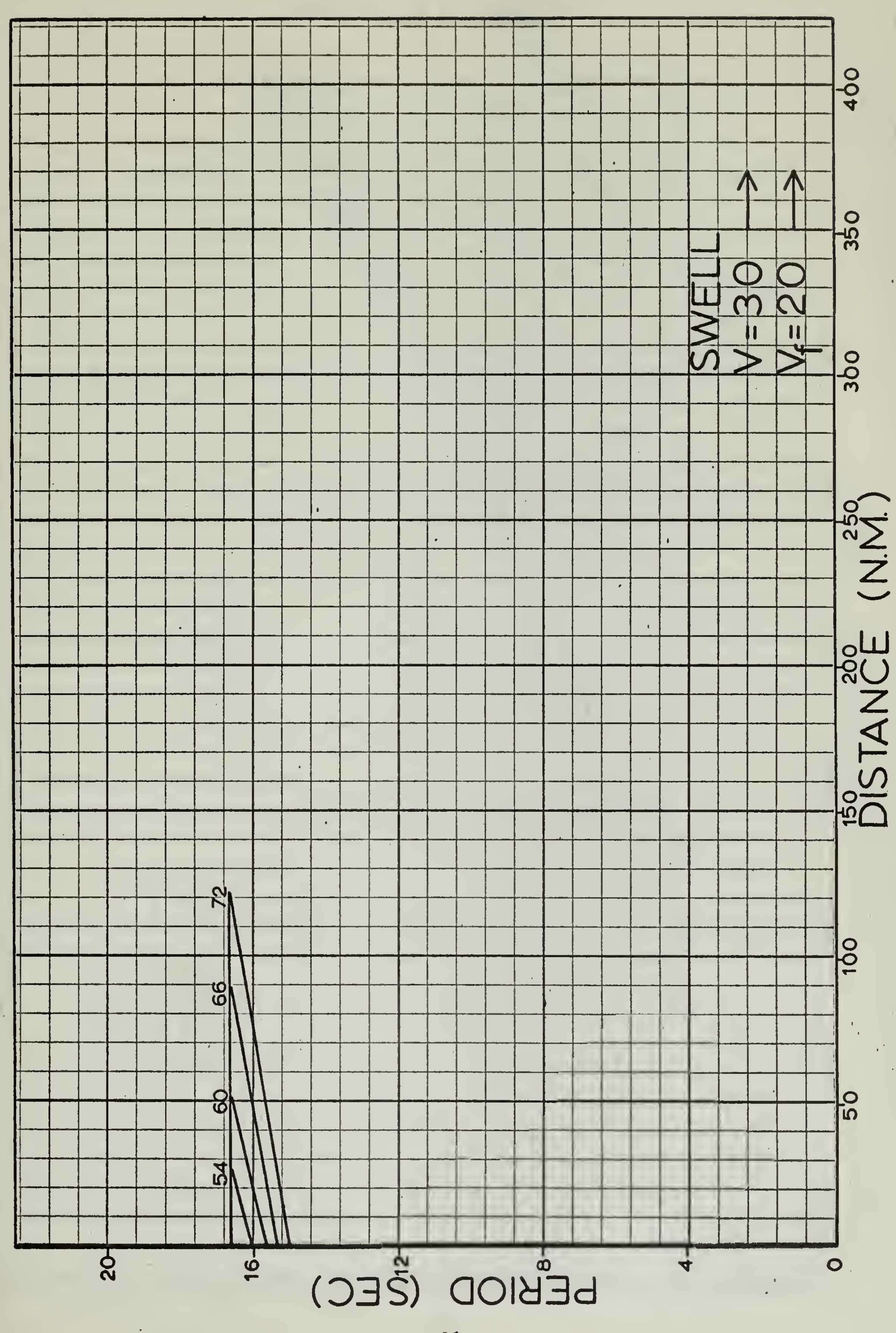
PERIOD (SEC)
20
16
12
8
4
0
30
36
72
24
18
12
6
400
350
300
250
200
150
100
50
DISTANCE (N.M.)
SUMDEL
V = 30
$V_f$ = 15

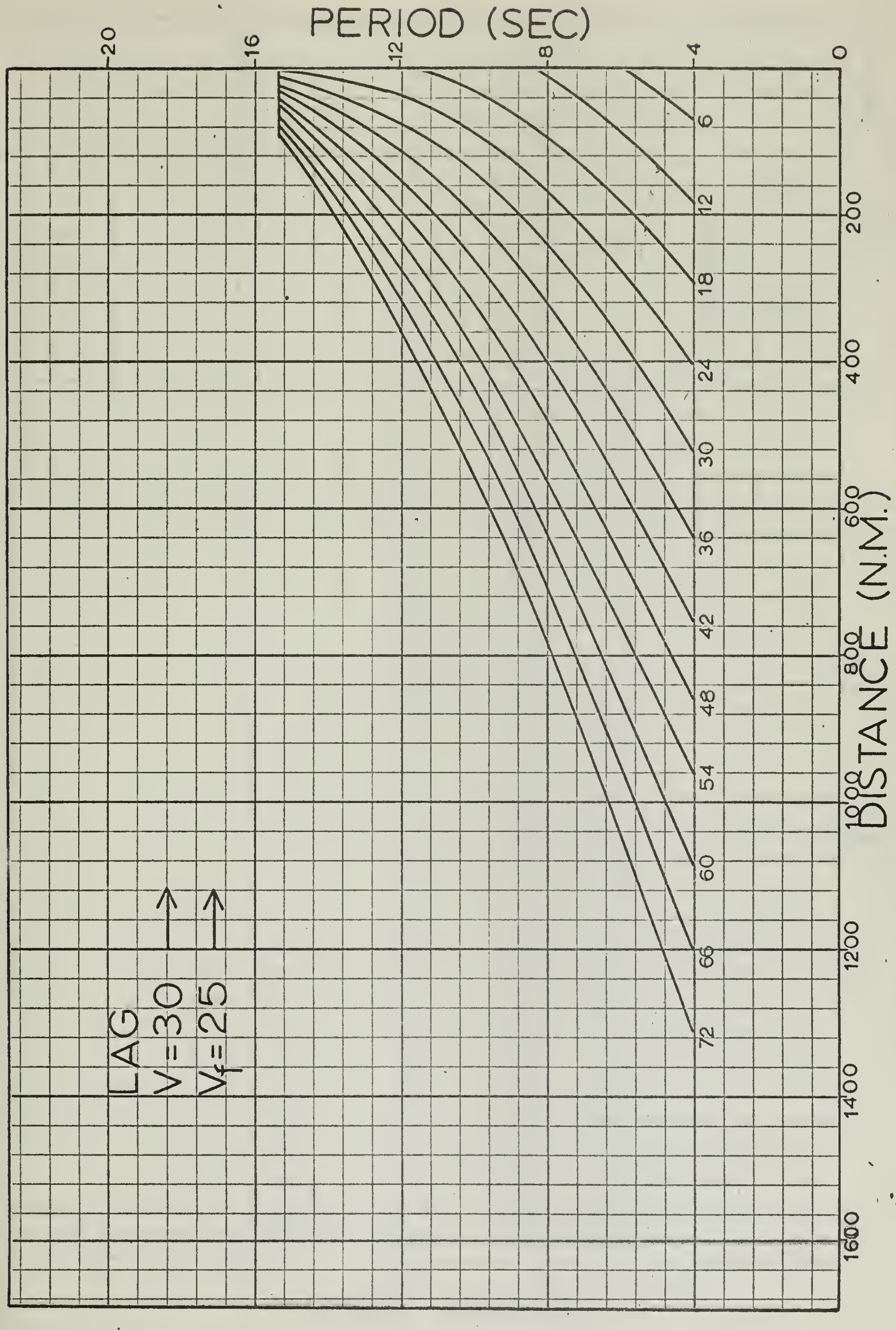

30
36
42
48
54
60
66
72
20
16
12
8
4
0
PERIOD (SEC)
100
200
300
400
500
600
700
800
DISTANCE (N.M.)
SWELL
V = 30 →
Vf = 15 →

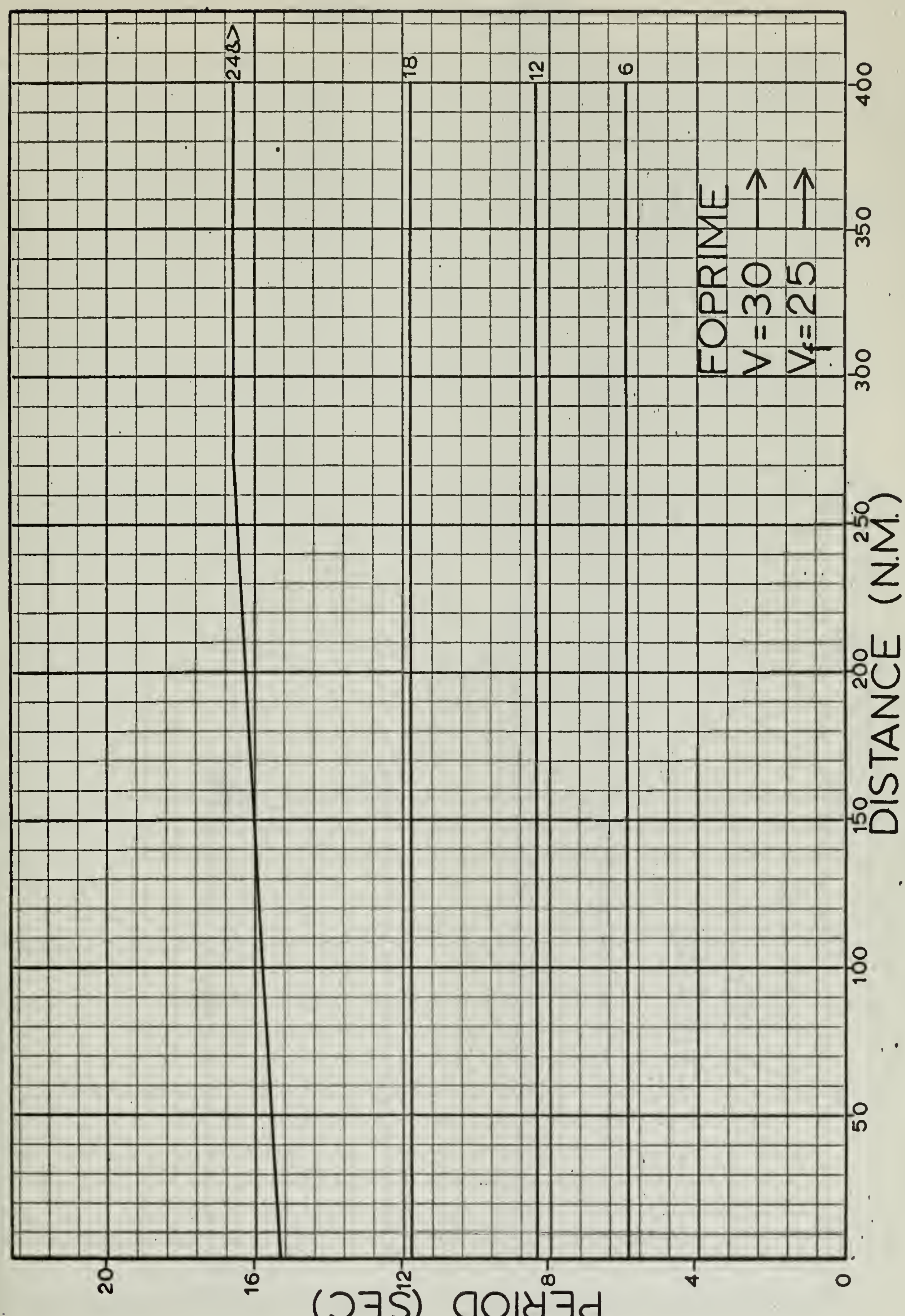

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
125
250
375
500
625
750
875
1000
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 30
V$_f$ = 20

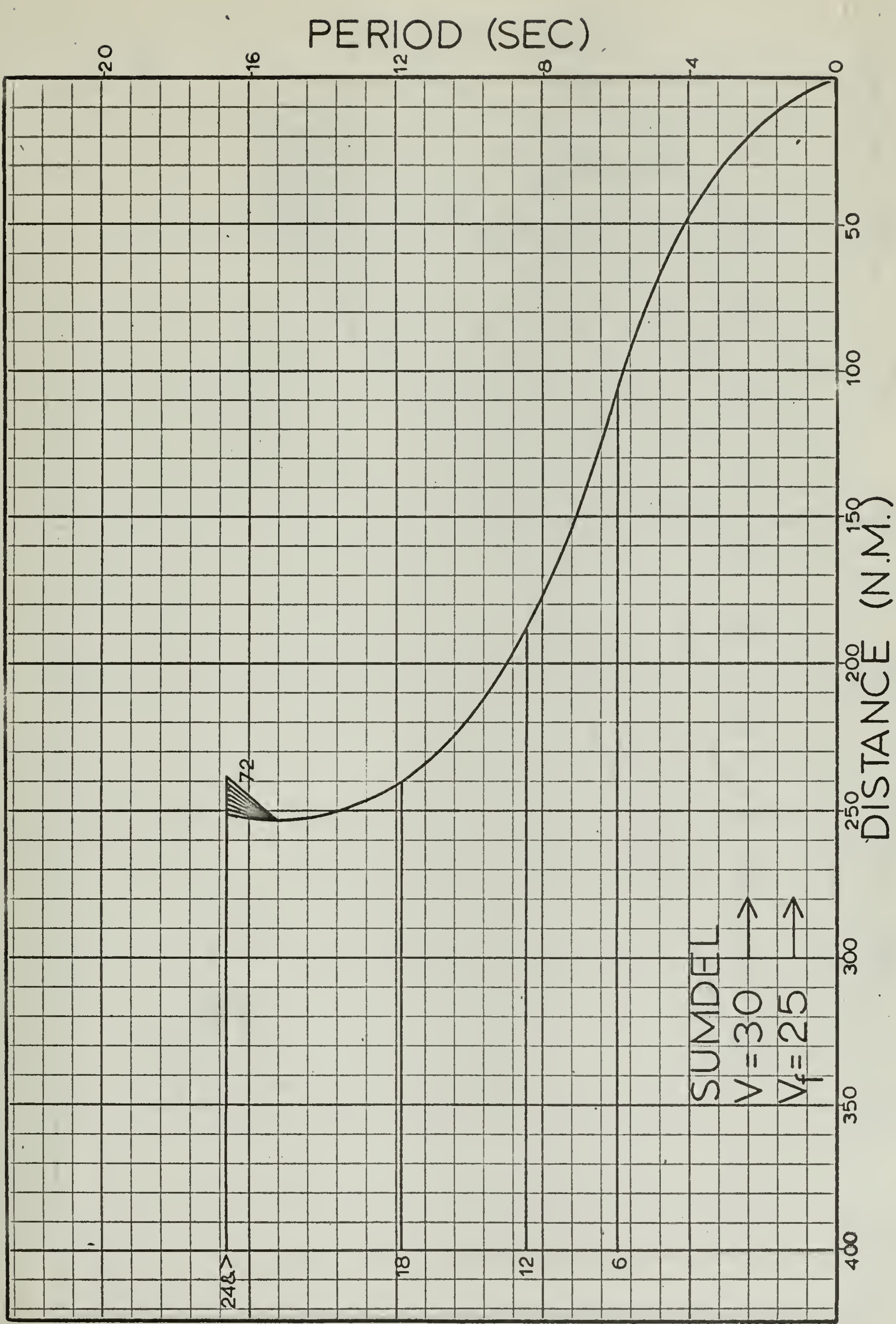

PERIOD (SEC)
20
16
12
8
4
0
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
24&>
18
12
6
FOPRIME
V=30
Vf=20

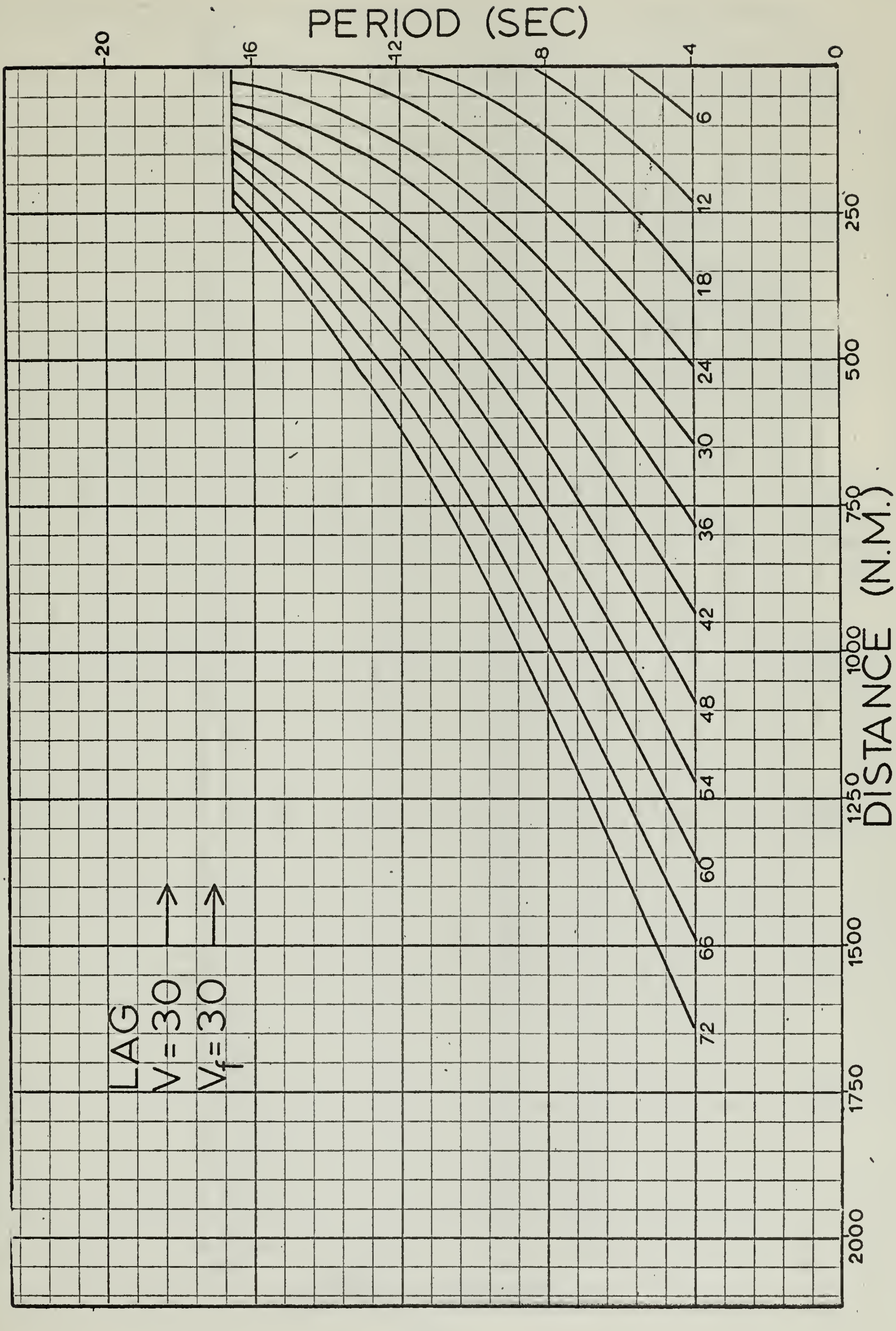

PERIOD (SEC)
20
16
12
8
4
0
54
72
42
30
DISTANCE (N.M.)
50
100
150
200
250
300
350
400
24&
18
12
6
SUMDEL
V = 30
Vf = 20


SWELL
V = 30
$V_f$ = 20
DISTANCE (N.M.)
PERIOD (SEC)
0
4
8
12
16
20
50
100
150
200
250
300
350
400
54
60
66
72

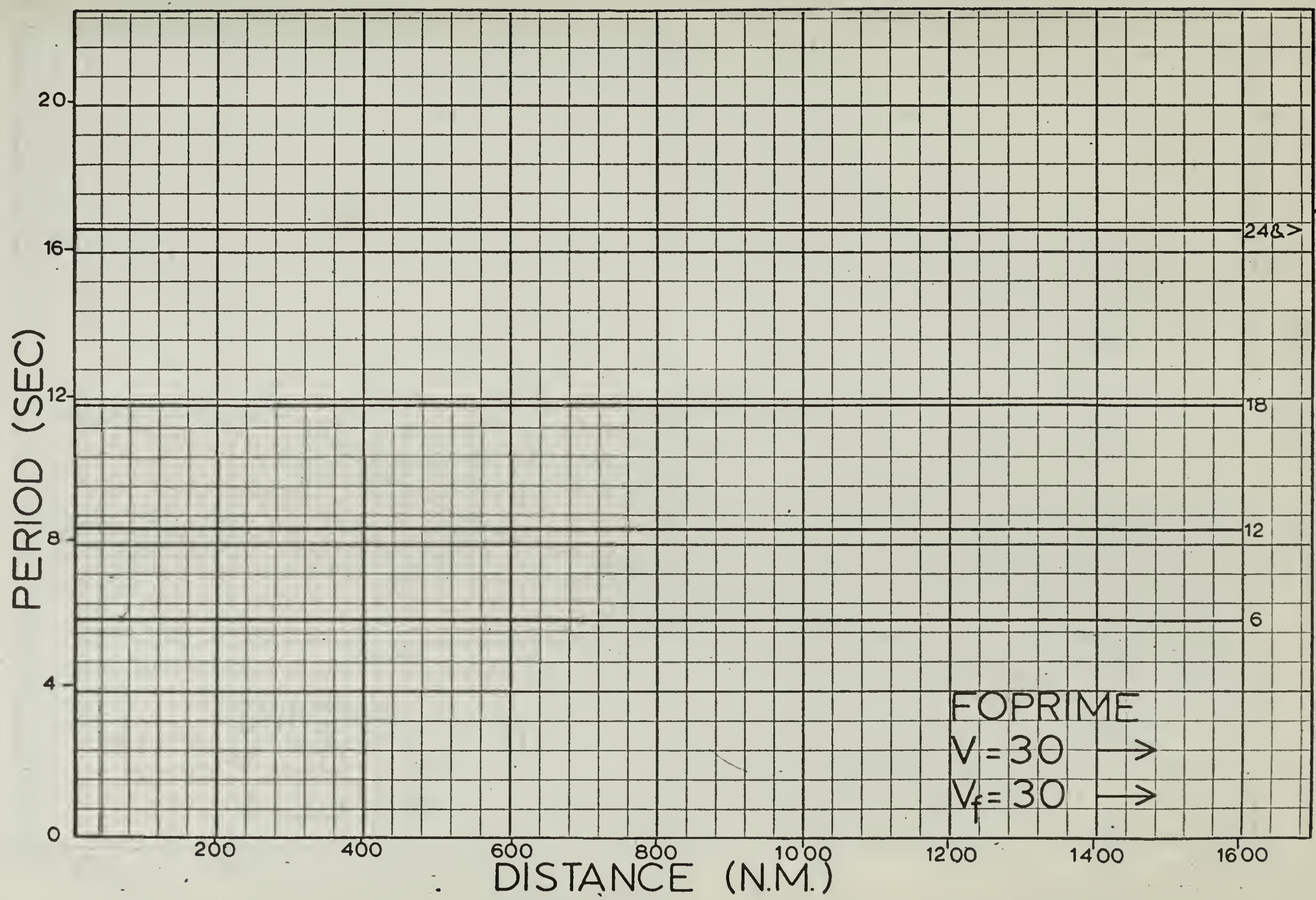

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 30
V_f = 25

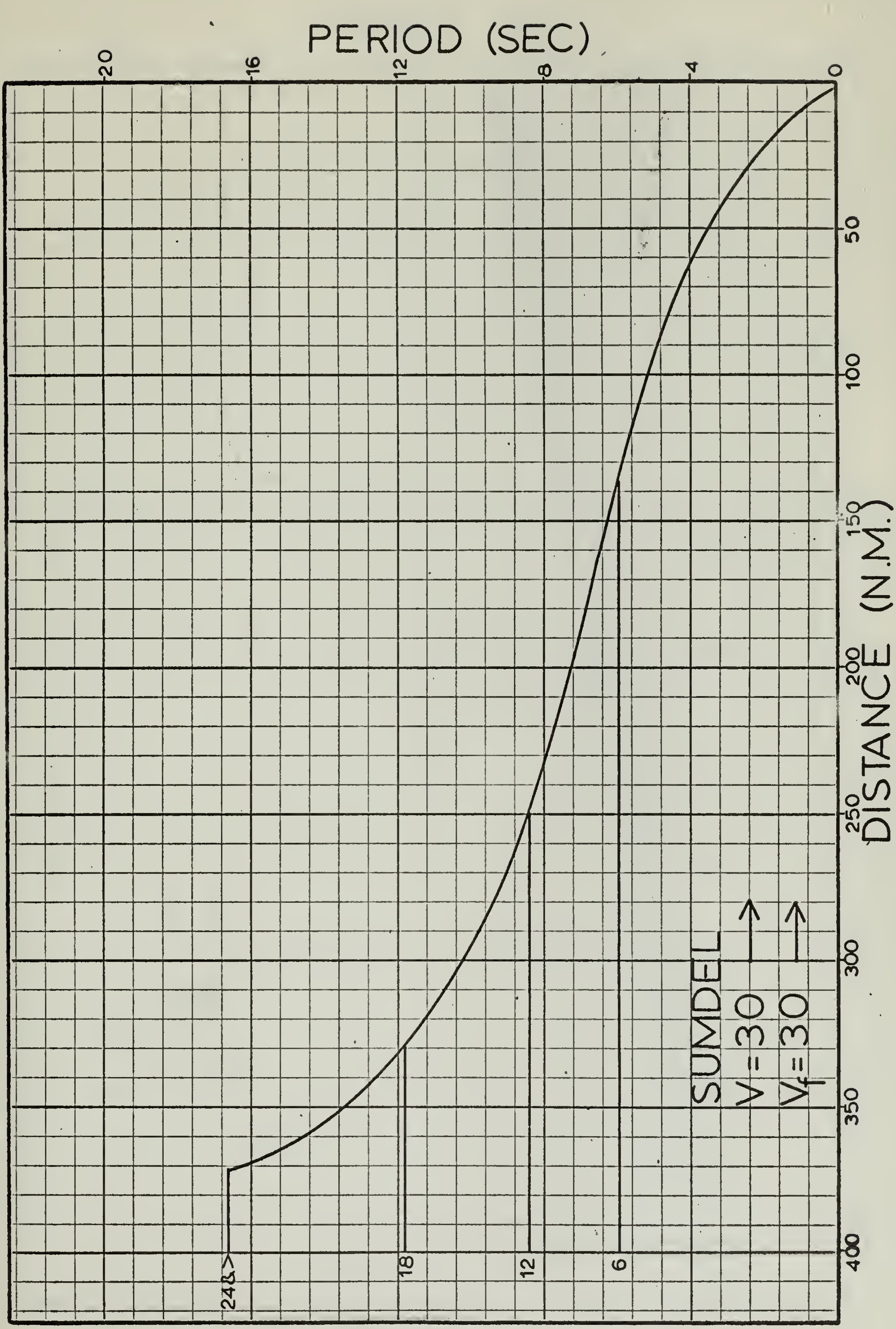

PERIOD (SEC)
DISTANCE (N.M.)
FOPRIME
V = 30
V_f = 25
24
18
12
6
0
4
8
12
16
20
50
100
150
200
250
300
350
400


PERIOD (SEC)
20
16
12
8
4
0
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
72
24&>
18
12
6
SUMDEL
V = 30
V_f = 25

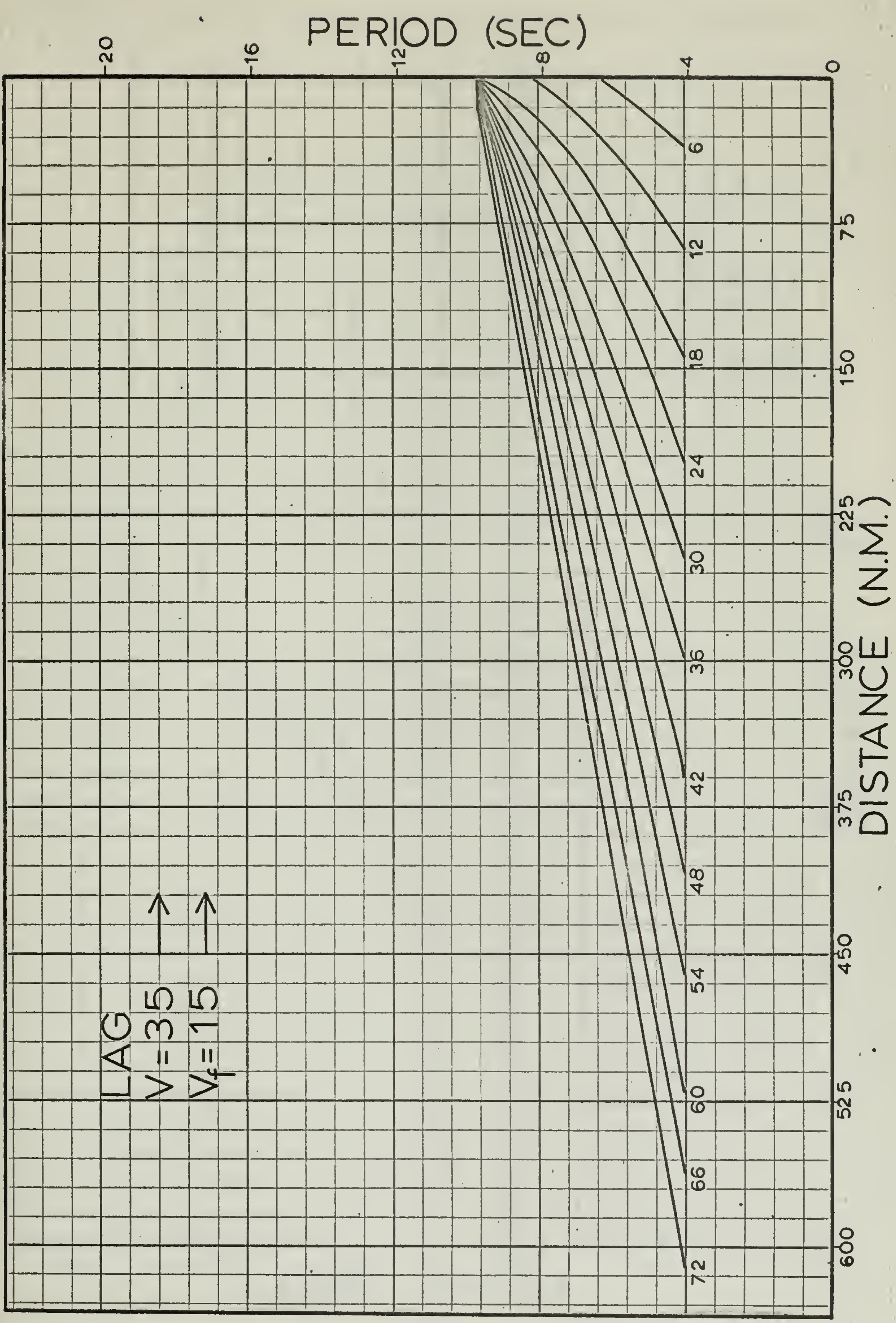


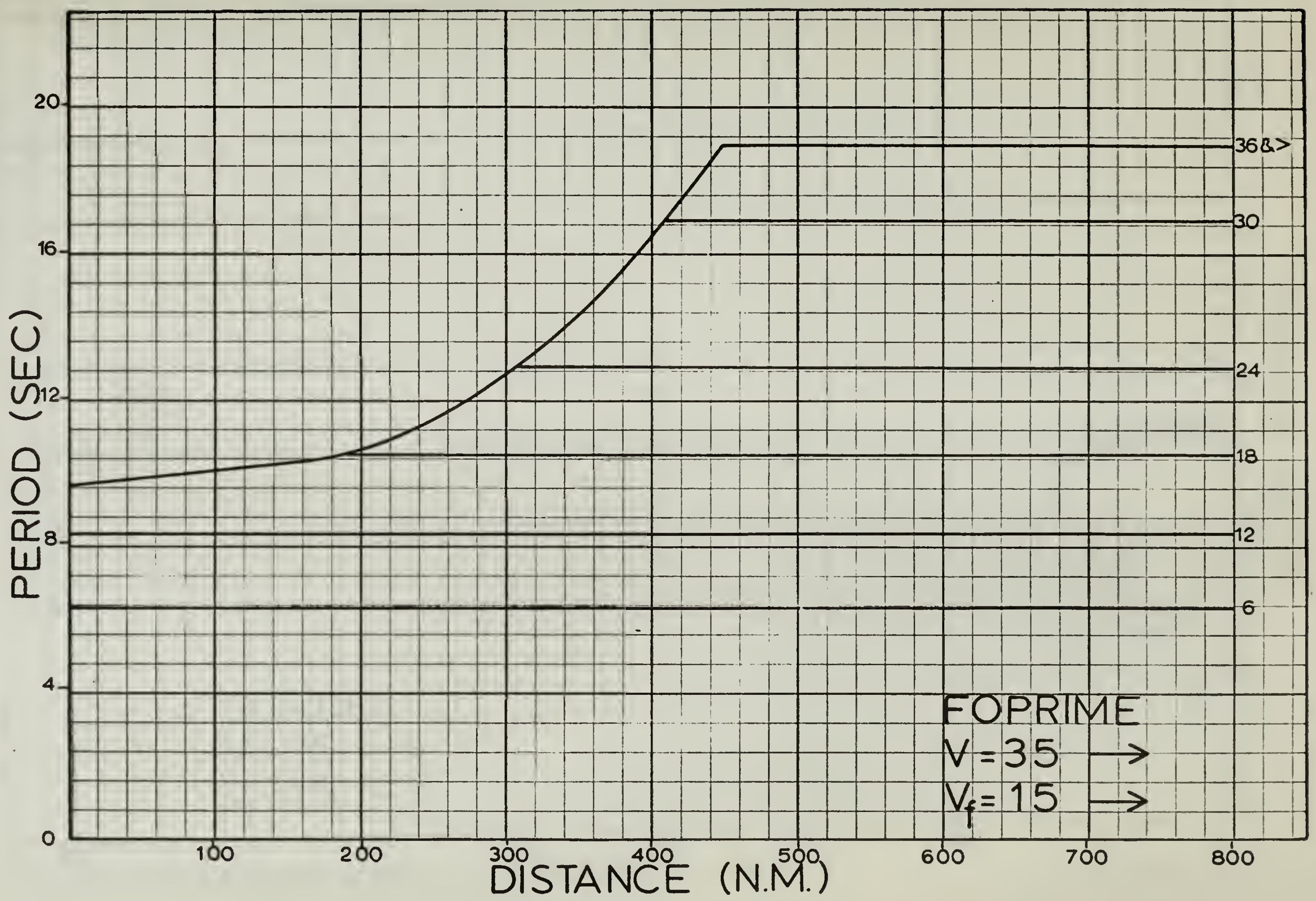
PERIOD (SEC)
20
16
12
8
4
0
6
12
18
24
30
36
42
48
54
60
66
72
250
500
750
1000
1250
1500
1750
2000
DISTANCE (N.M.)
LAG
V = 30
$V_f$ = 30


20
16
12
8
4
0
PERIOD (SEC)
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
24&>
18
12
6
FOPRIME
V = 30
V_f = 30

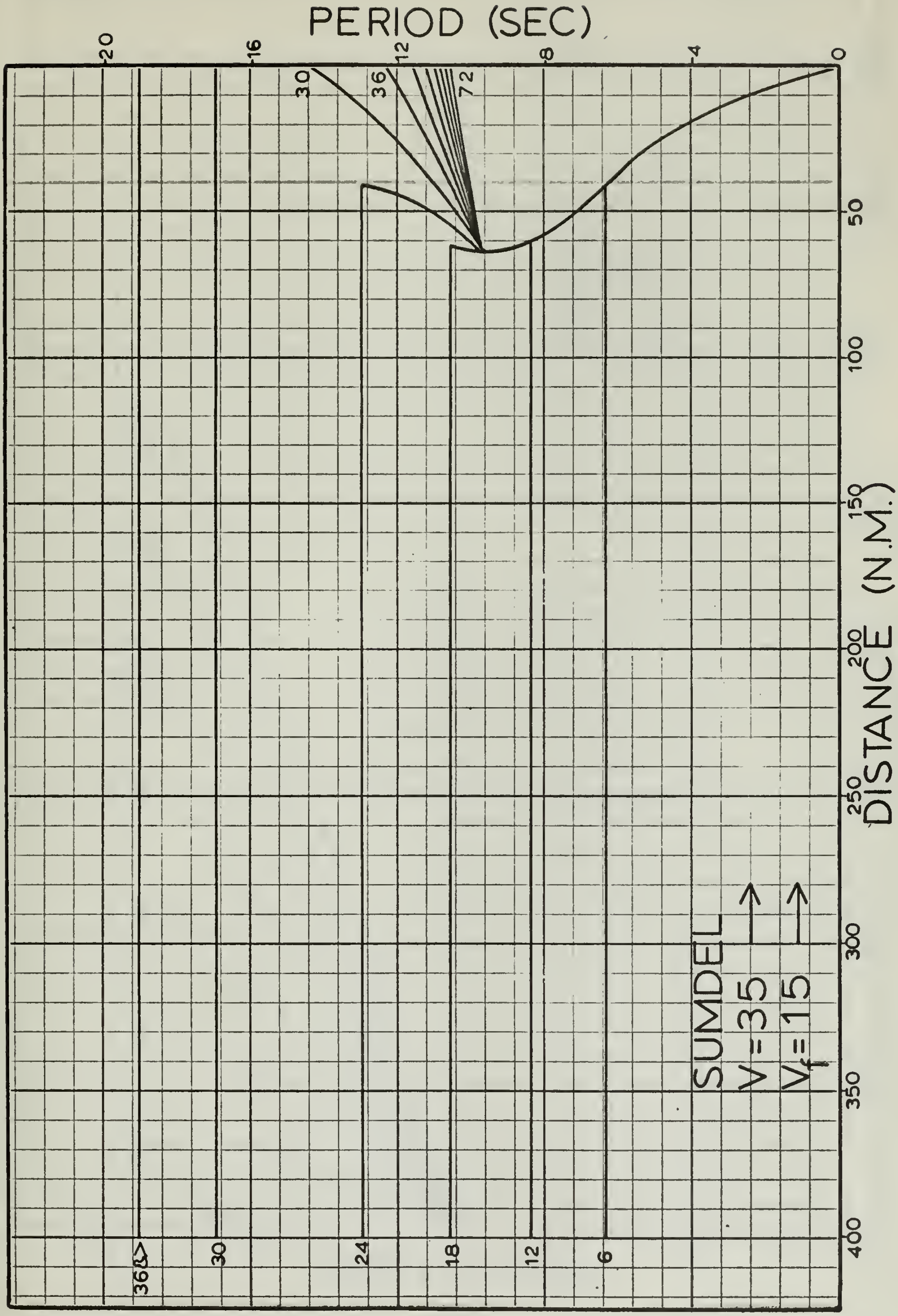


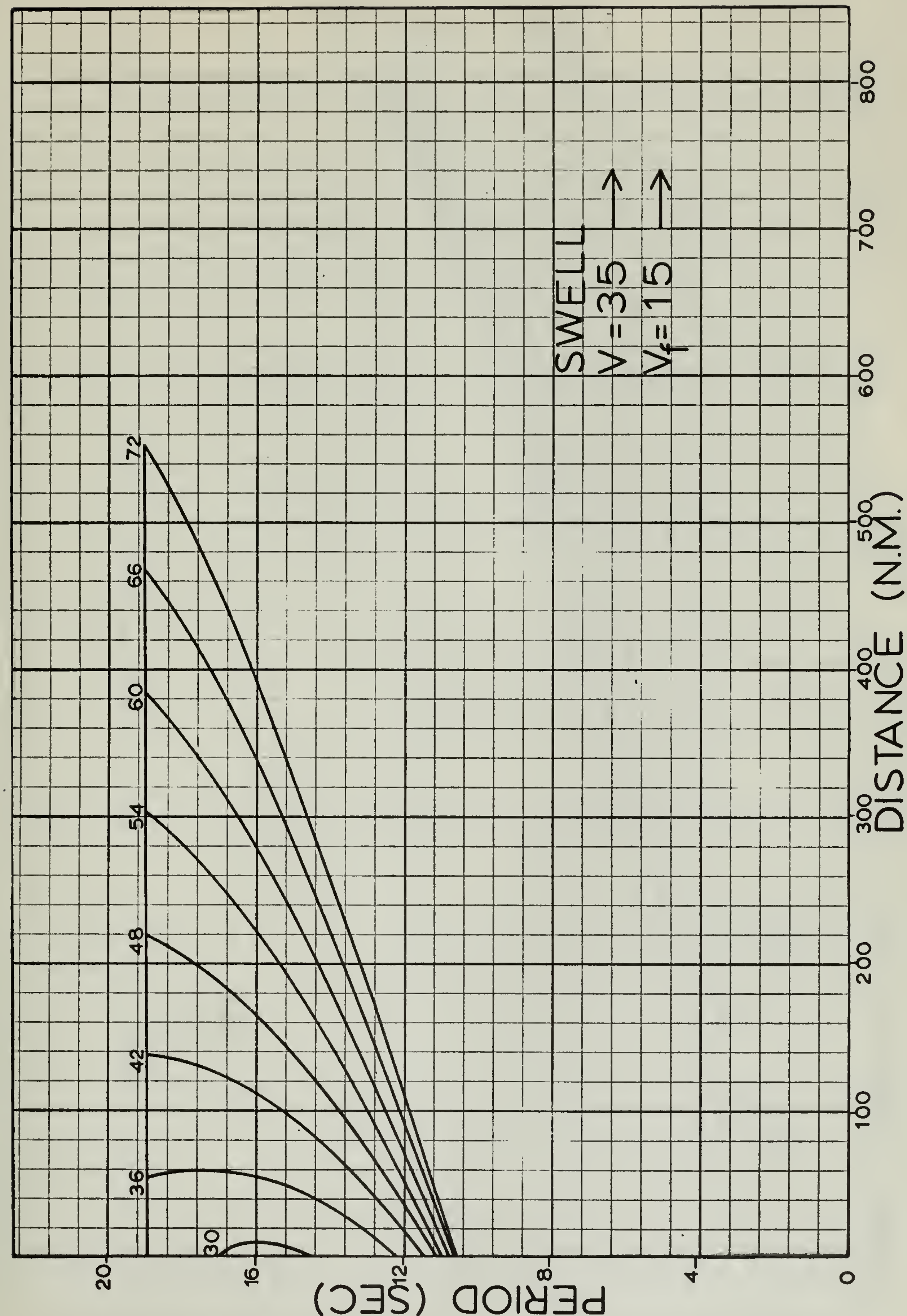
PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
50
100
150
200
250
300
350
400
SUMDEL
V = 30
$V_f$ = 30
24>
18
12
6

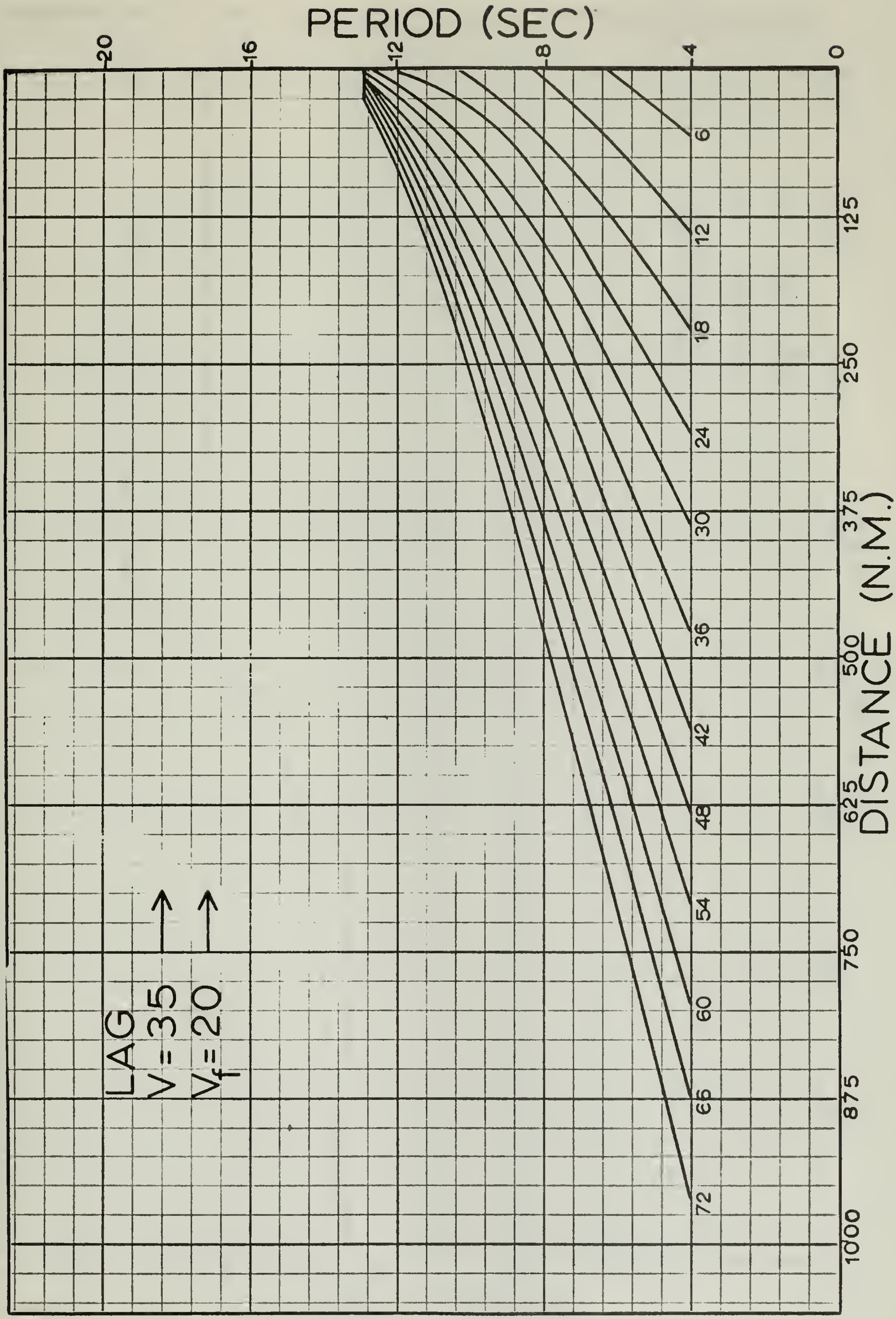

PERIOD (SEC)
-20
-16
-12
-8
-4
0
75
150
225
300
375
450
525
600
DISTANCE (N.M.)
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 35
$V_f$ = 15



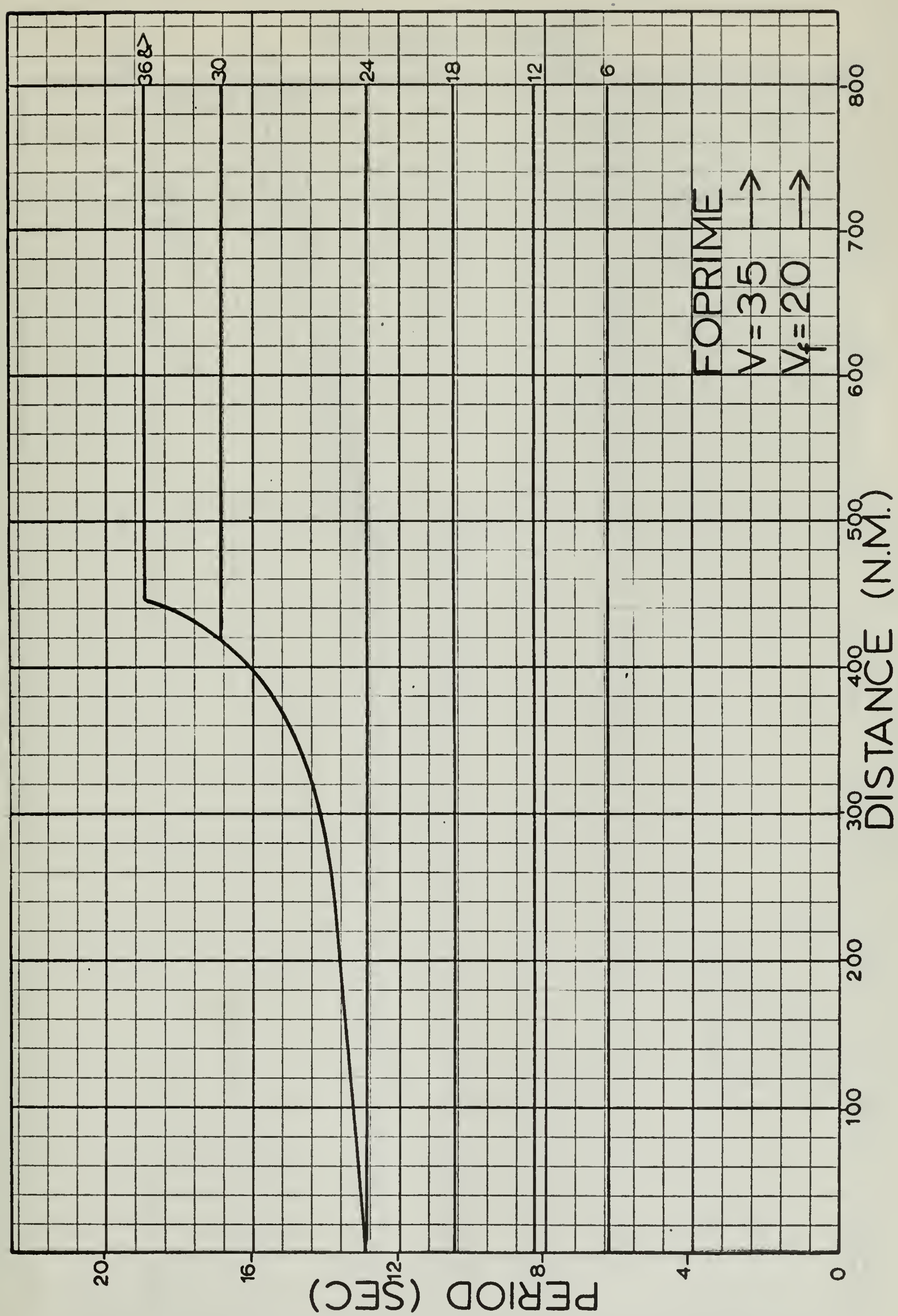
FOPRIME
V = 35
$V_f$ = 15
36 & >
30
24
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
100
200
300
400
500
600
700
800

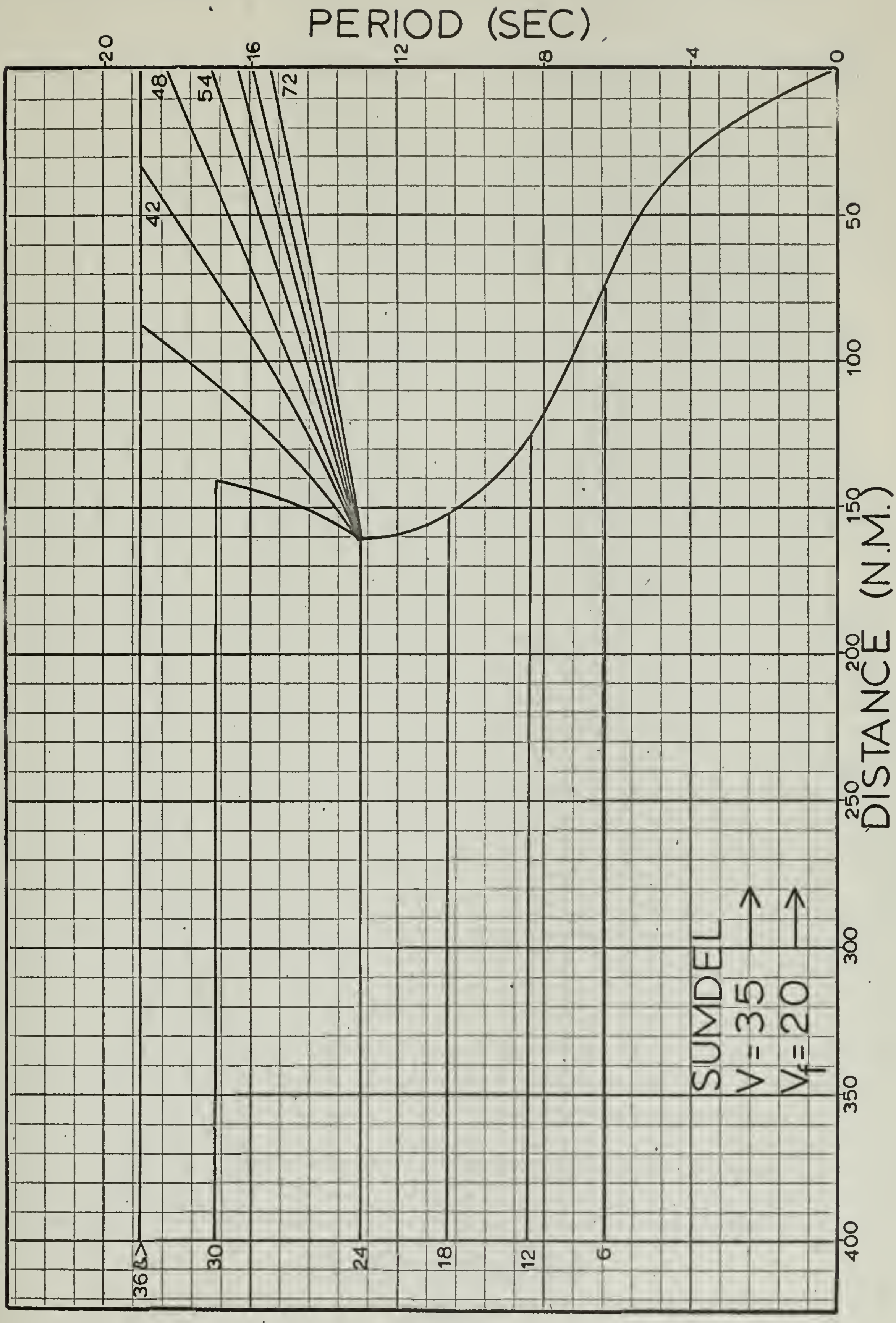

PERIOD (SEC)
20
16
12
8
4
0
30
36
72
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
SUMDEL
V = 35
V = 15
36
30
24
18
12
6


SWELL
V = 35
$V_f$ = 15
30
36
42
48
54
60
66
72
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
100
200
300
400
500
600
700
800

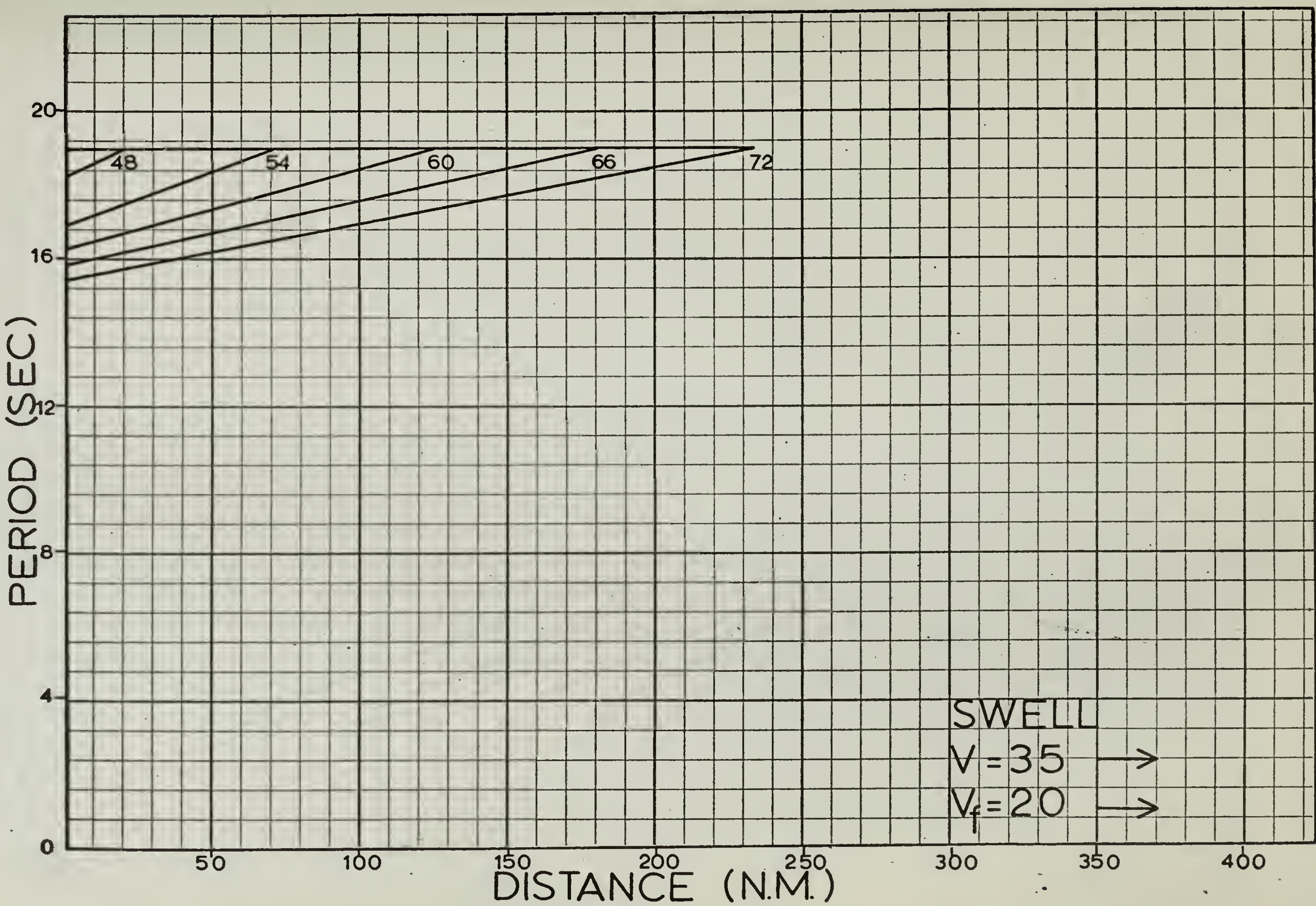


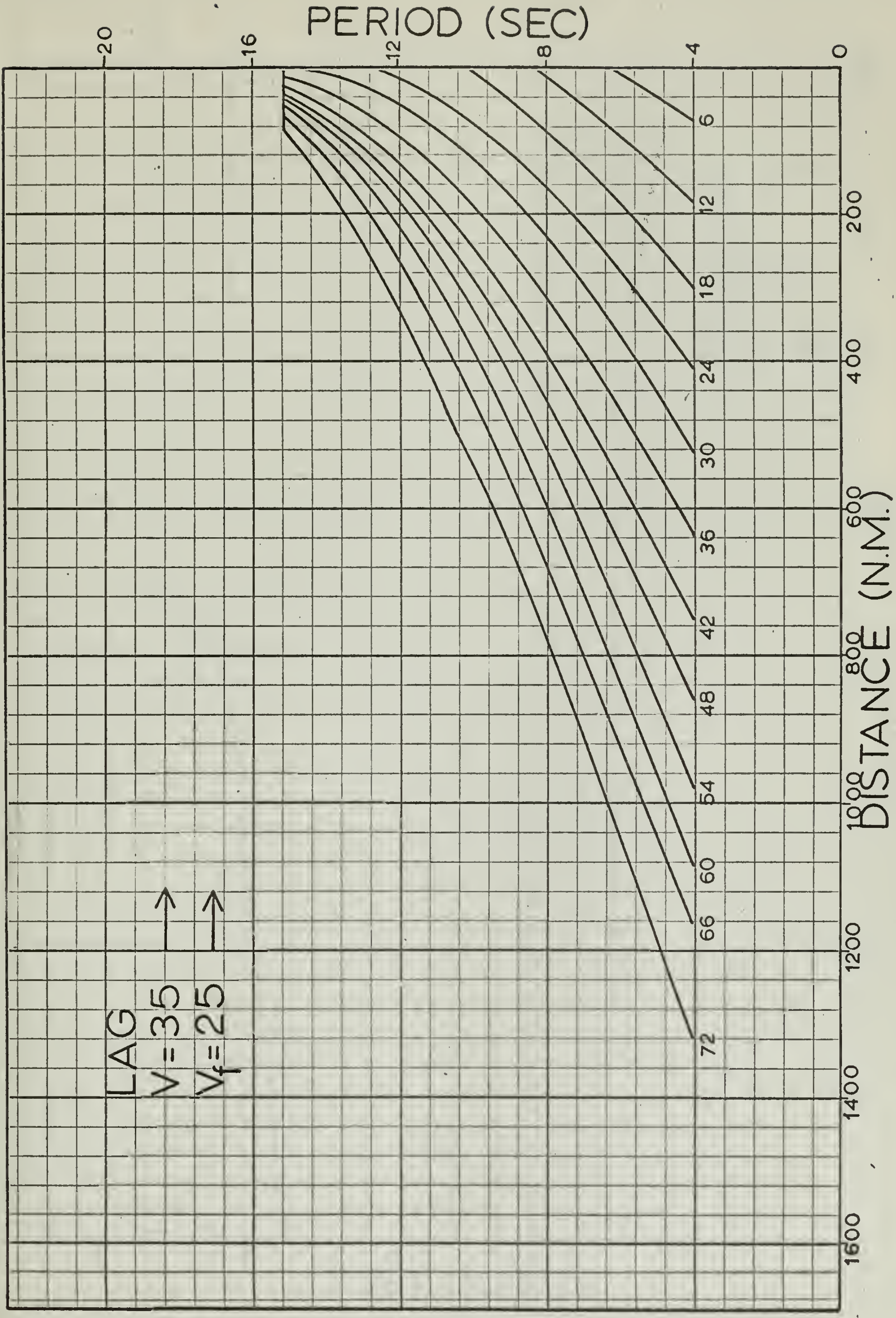
PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
125
250
375
500
625
750
875
1000
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 35
V_f = 20

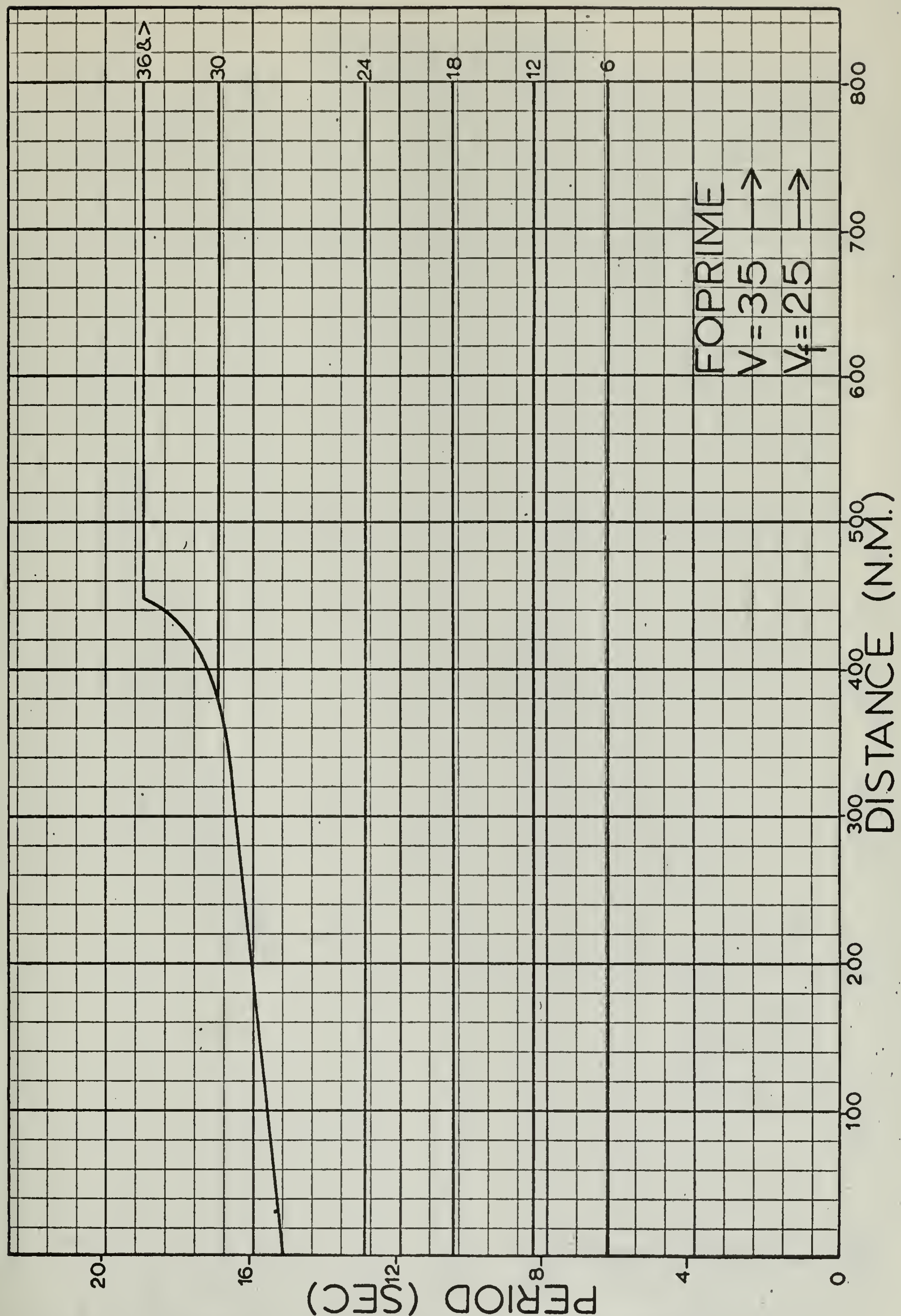

FOPRIME
V = 35 →
V_f = 20 →
36 & >
30
24
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
100
200
300
400
500
600
700
800

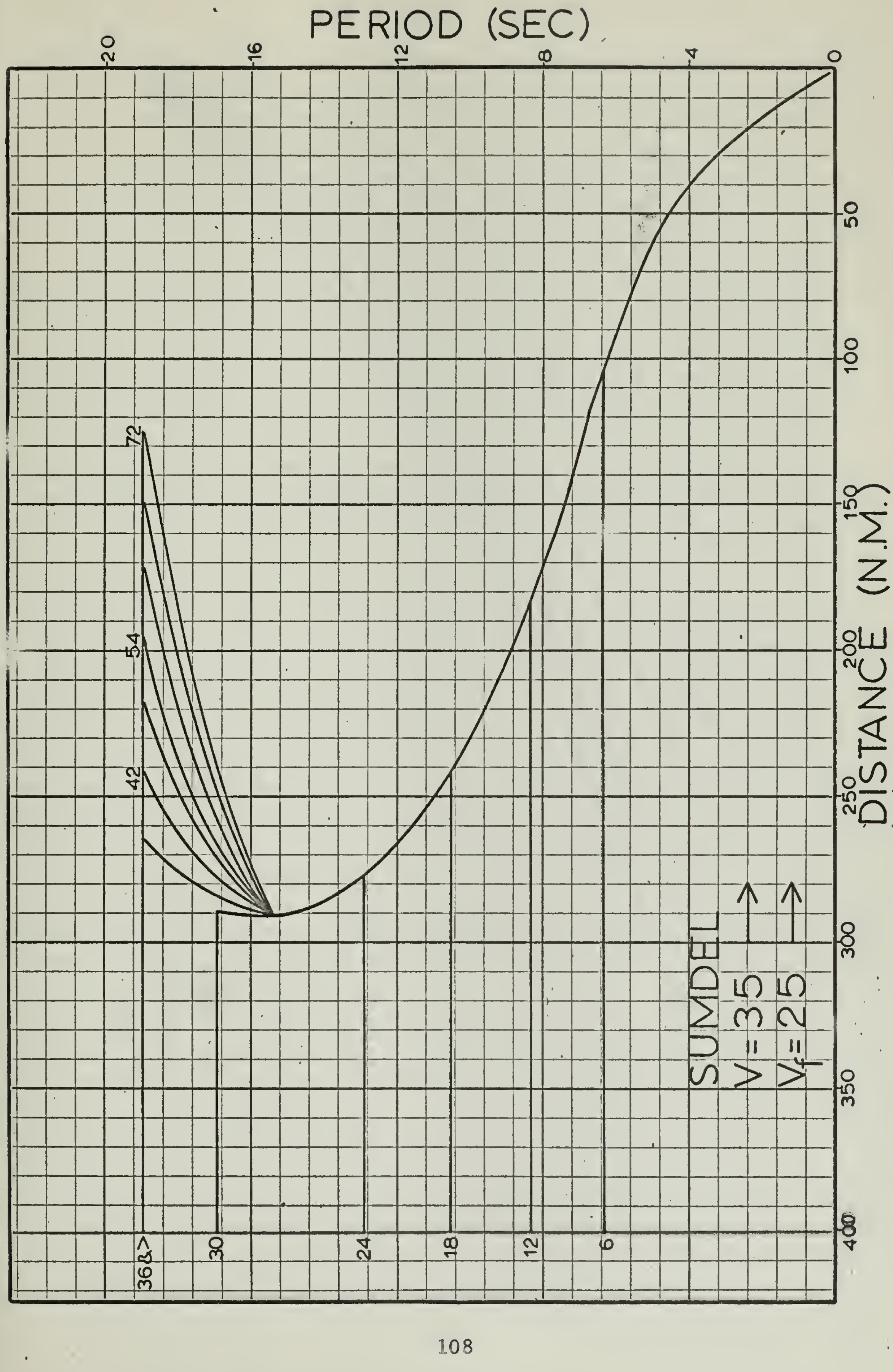


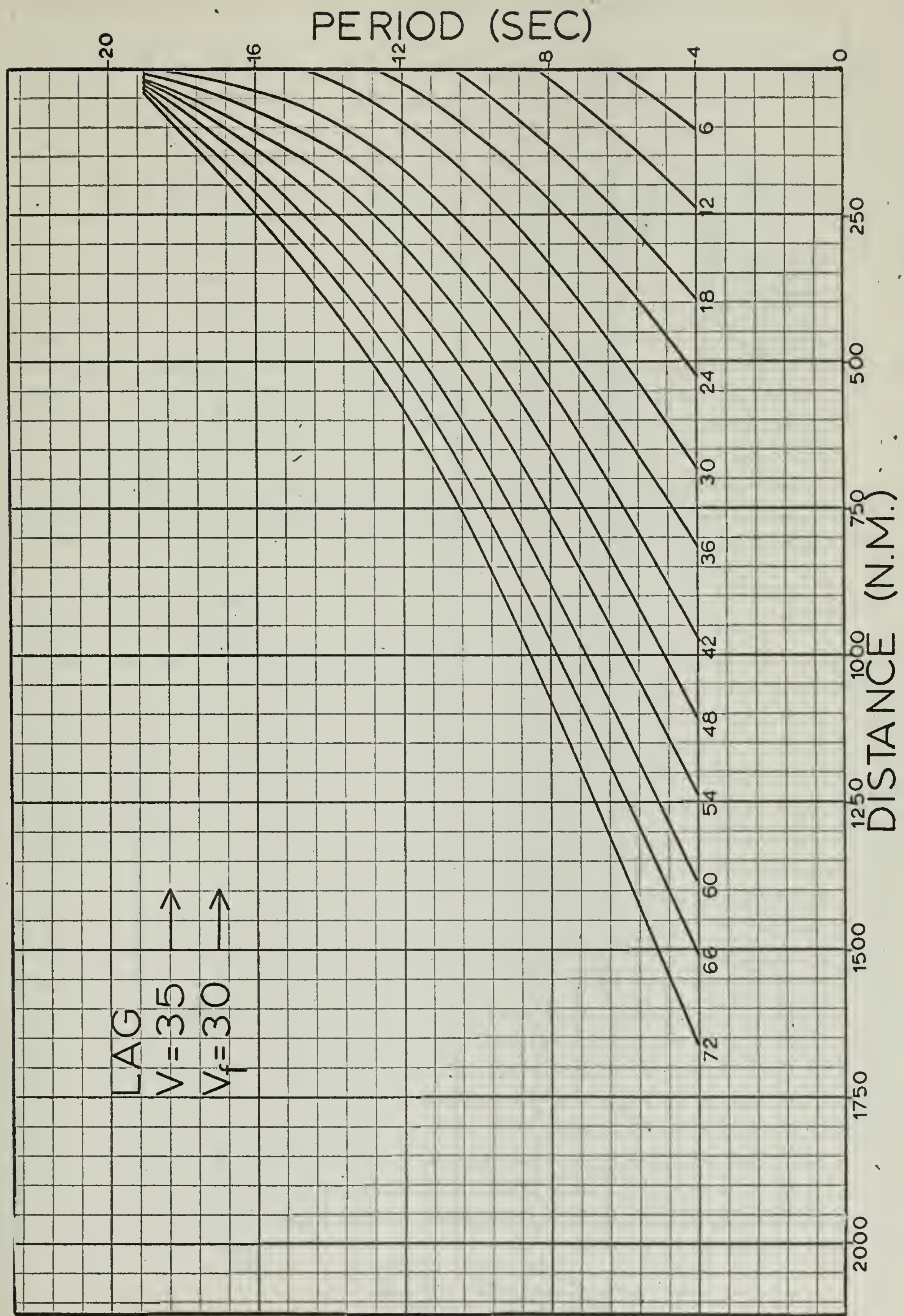
PERIOD (SEC)
DISTANCE (N.M.)
SUMDEL
V = 35 →
V_f = 20 →
20
16
12
8
4
0
50
100
150
200
250
300
350
400
36
30
24
18
12
6
42
48
54
72

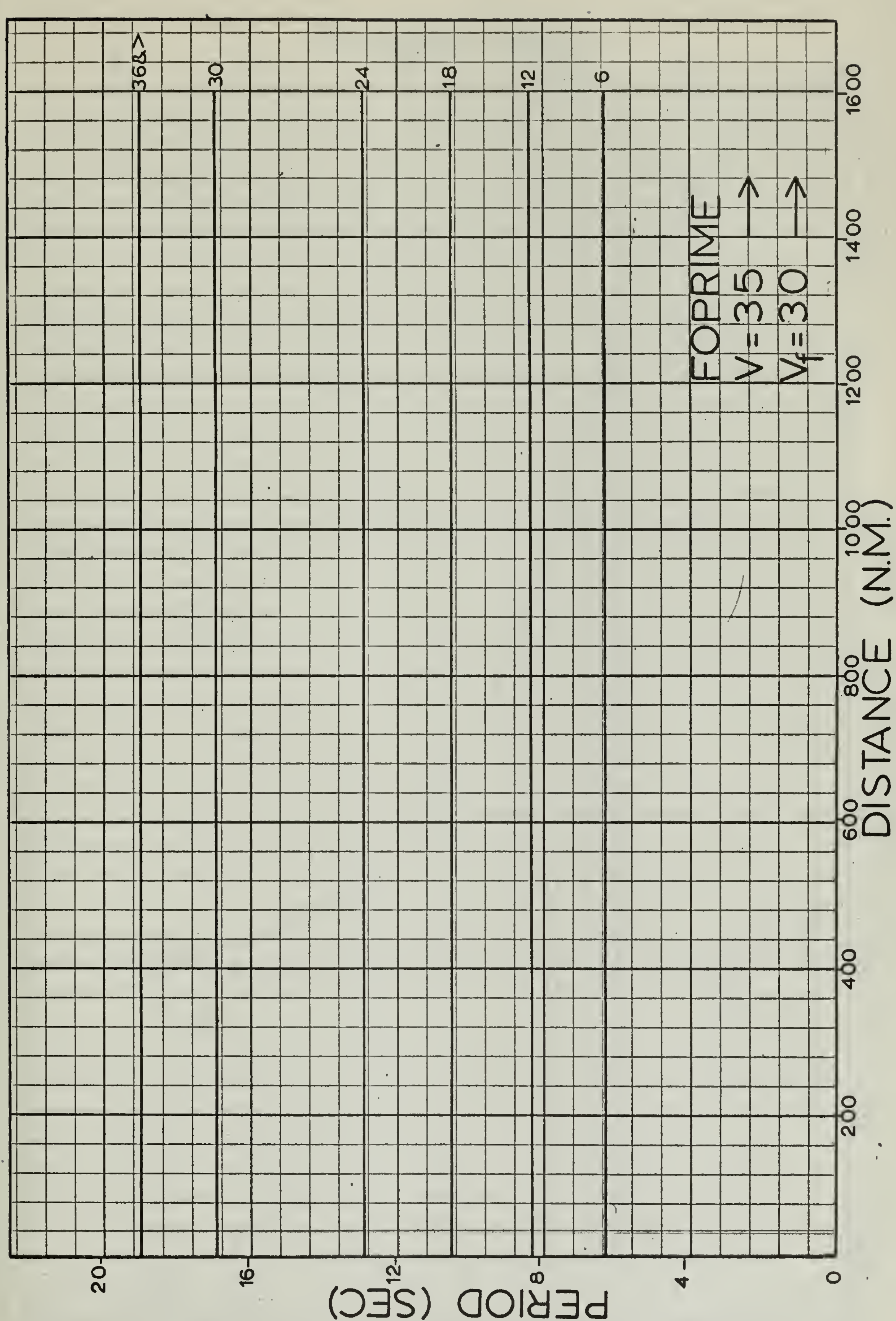

48
54
60
66
72
SWELL
$V = 35$
$V_f = 20$
PERIOD (SEC)
20
16
12
8
4
0
50
100
150
200
250
300
350
400
DISTANCE (N.M.)

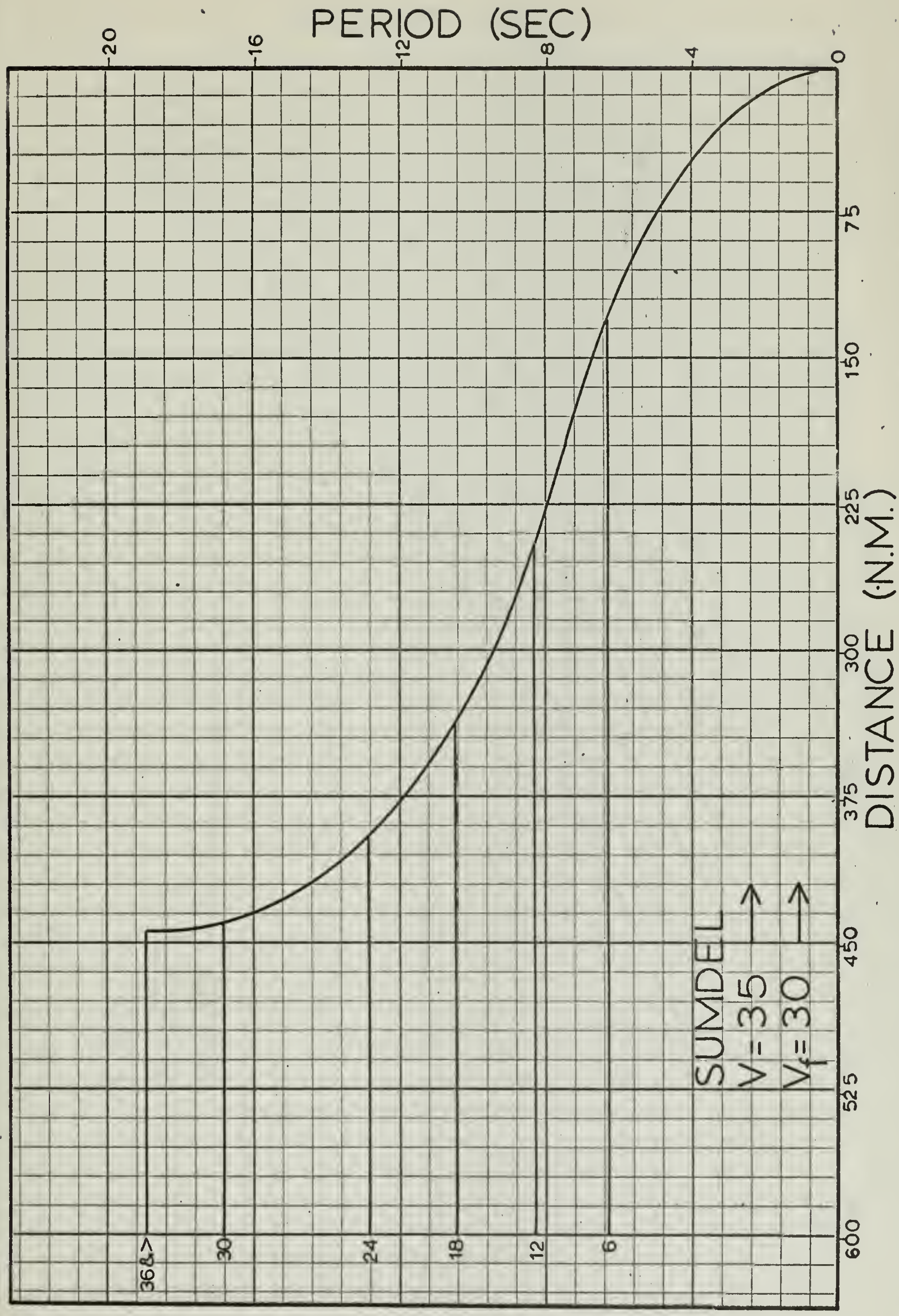

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 35
V_f = 25

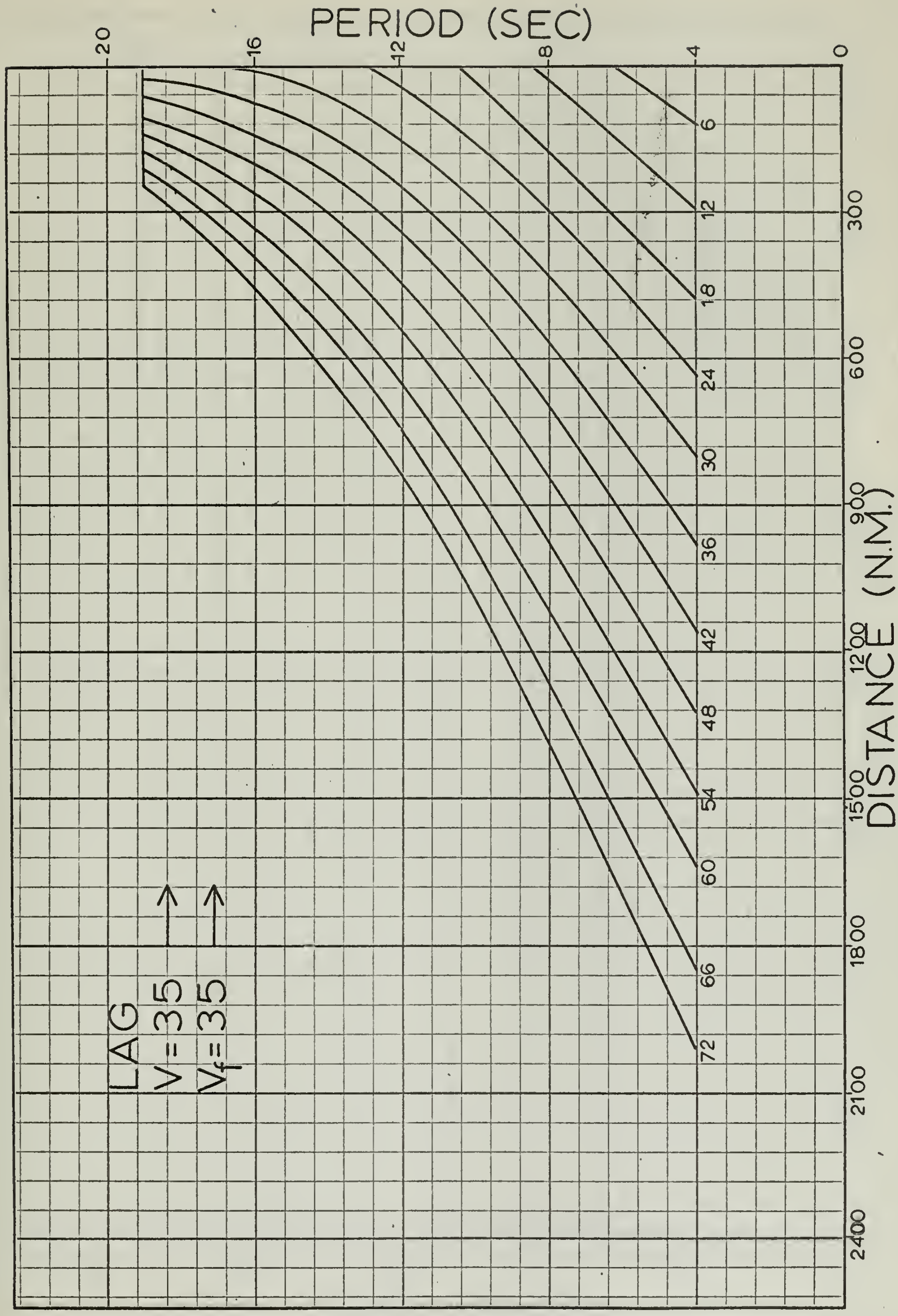

FOPRIME
V = 35 →
V_f = 25 →
36&>
30
24
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
100
200
300
400
500
600
700
800

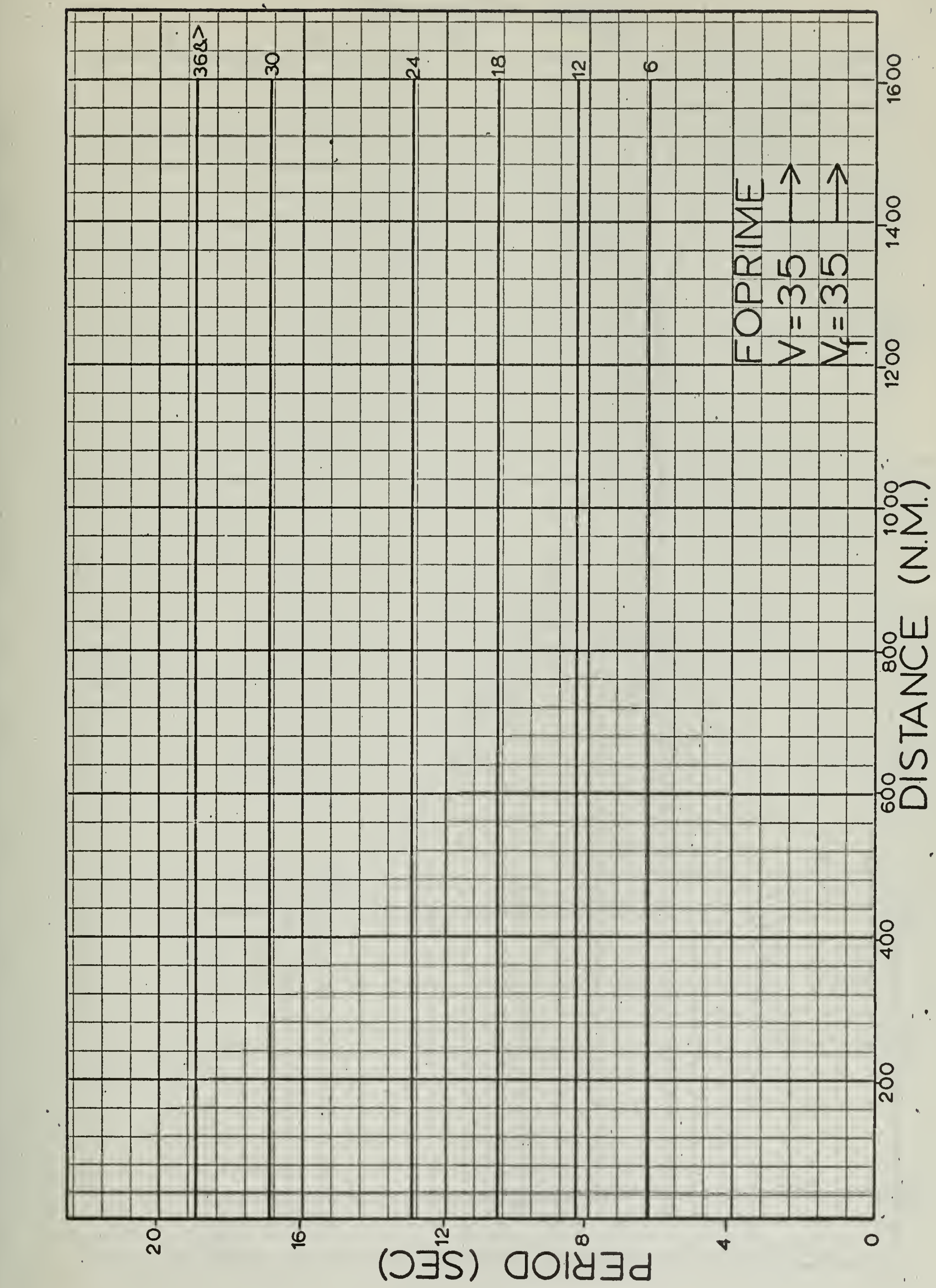

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
50
100
150
200
250
300
350
400
72
54
42
36&>
30
24
18
12
6
SUMDEL
V = 35
Vf = 25


PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
250
500
750
1000
1250
1500
1750
2000
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 35
V_f = 30

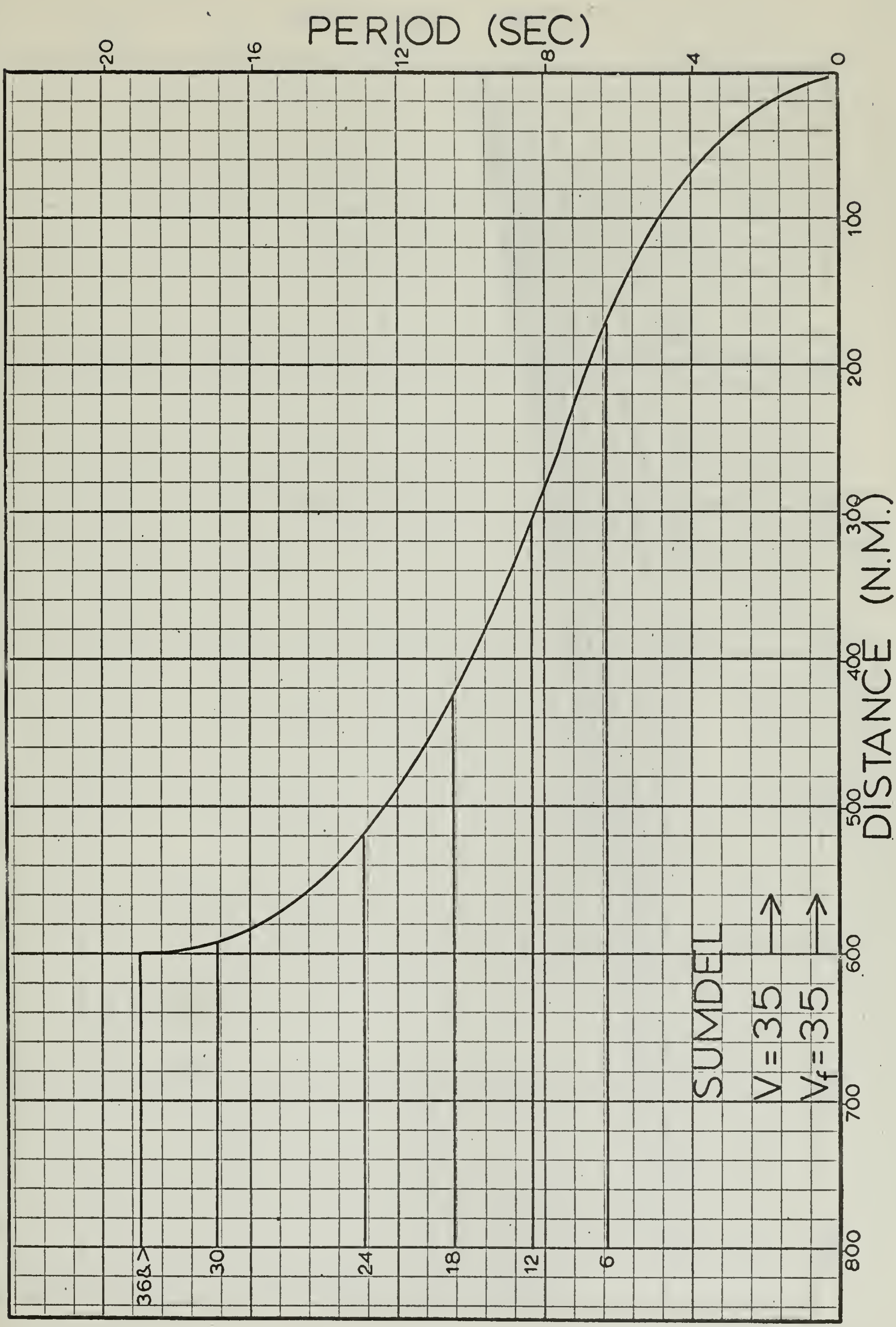

FOPRIME
V = 35
$V_f$ = 30
36&>
30
24
18
12
6
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
PERIOD (SEC)
0
4
8
12
16
20

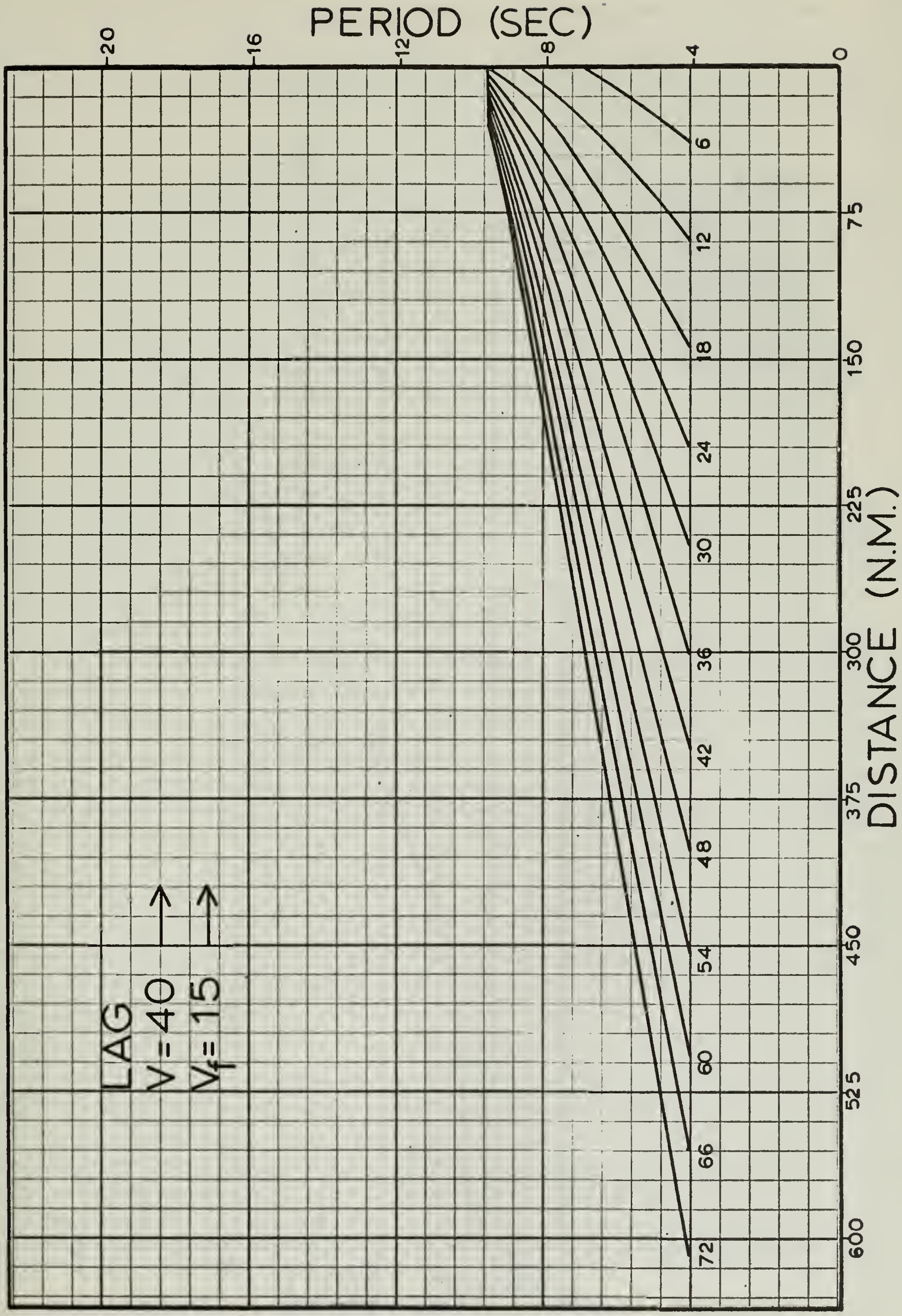

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
75
150
225
300
375
450
525
600
SUMDEL
V= 35
V_f= 30
36&>
30
24
18
12
6

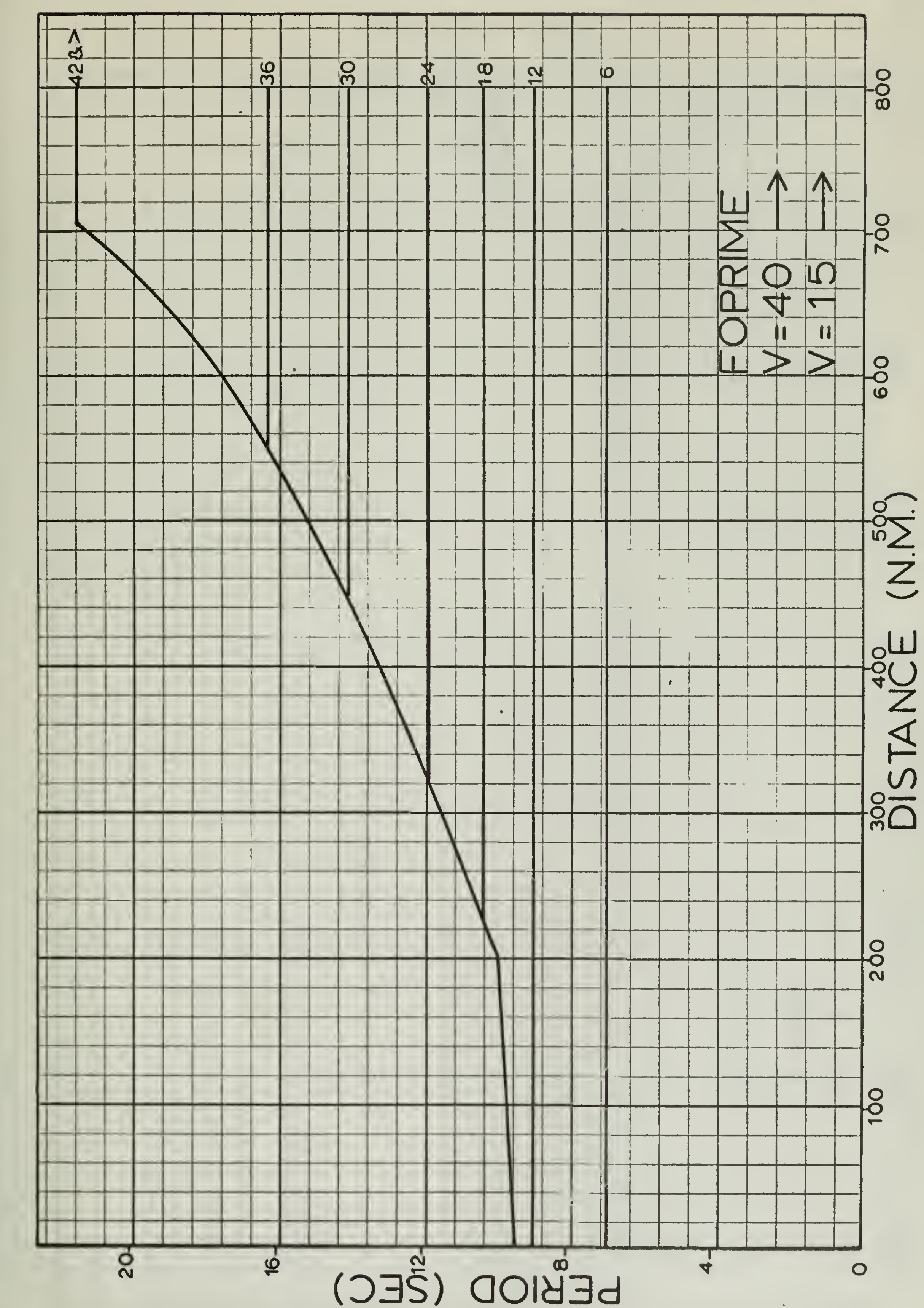

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
300
600
900
1200
1500
1800
2100
2400
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 35
V_f = 35

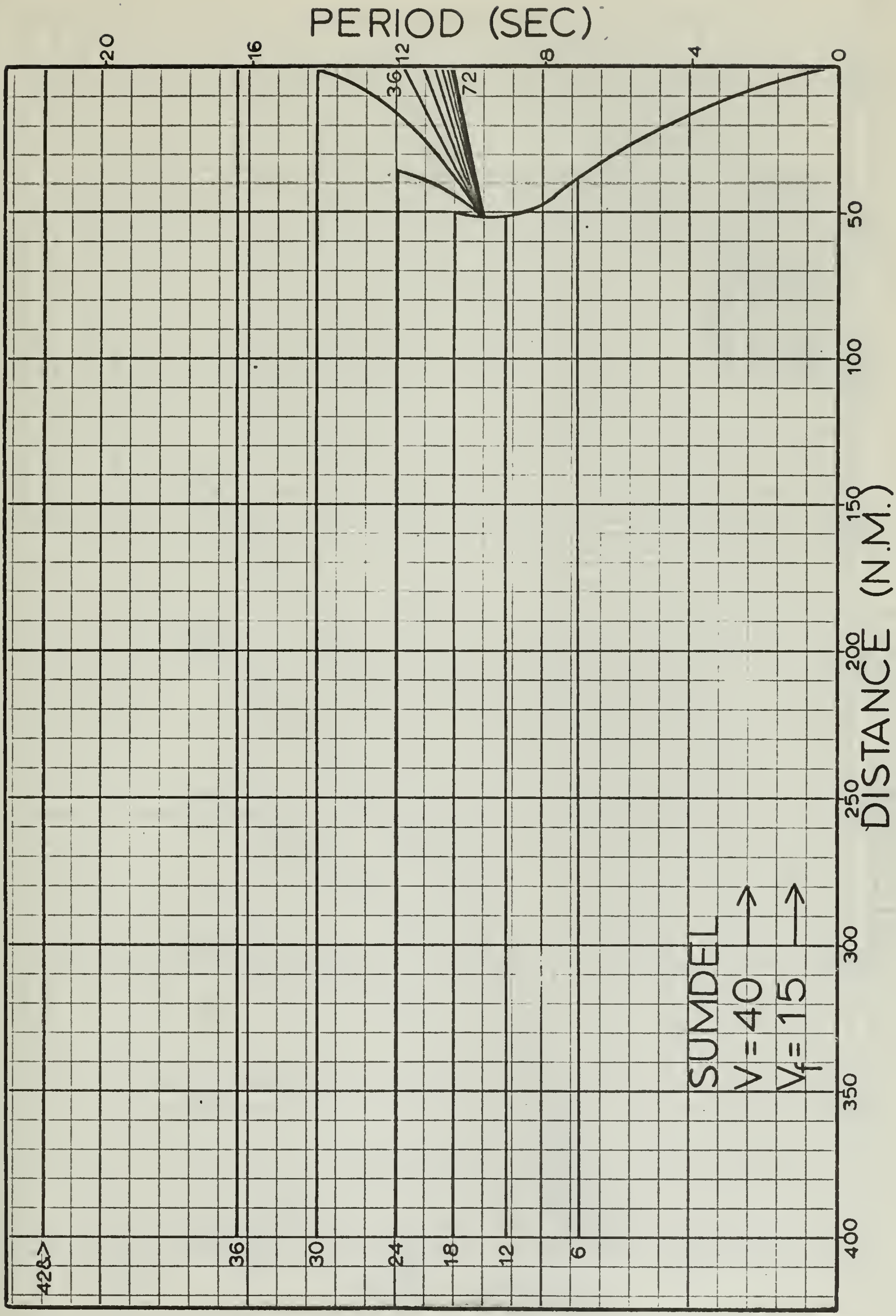


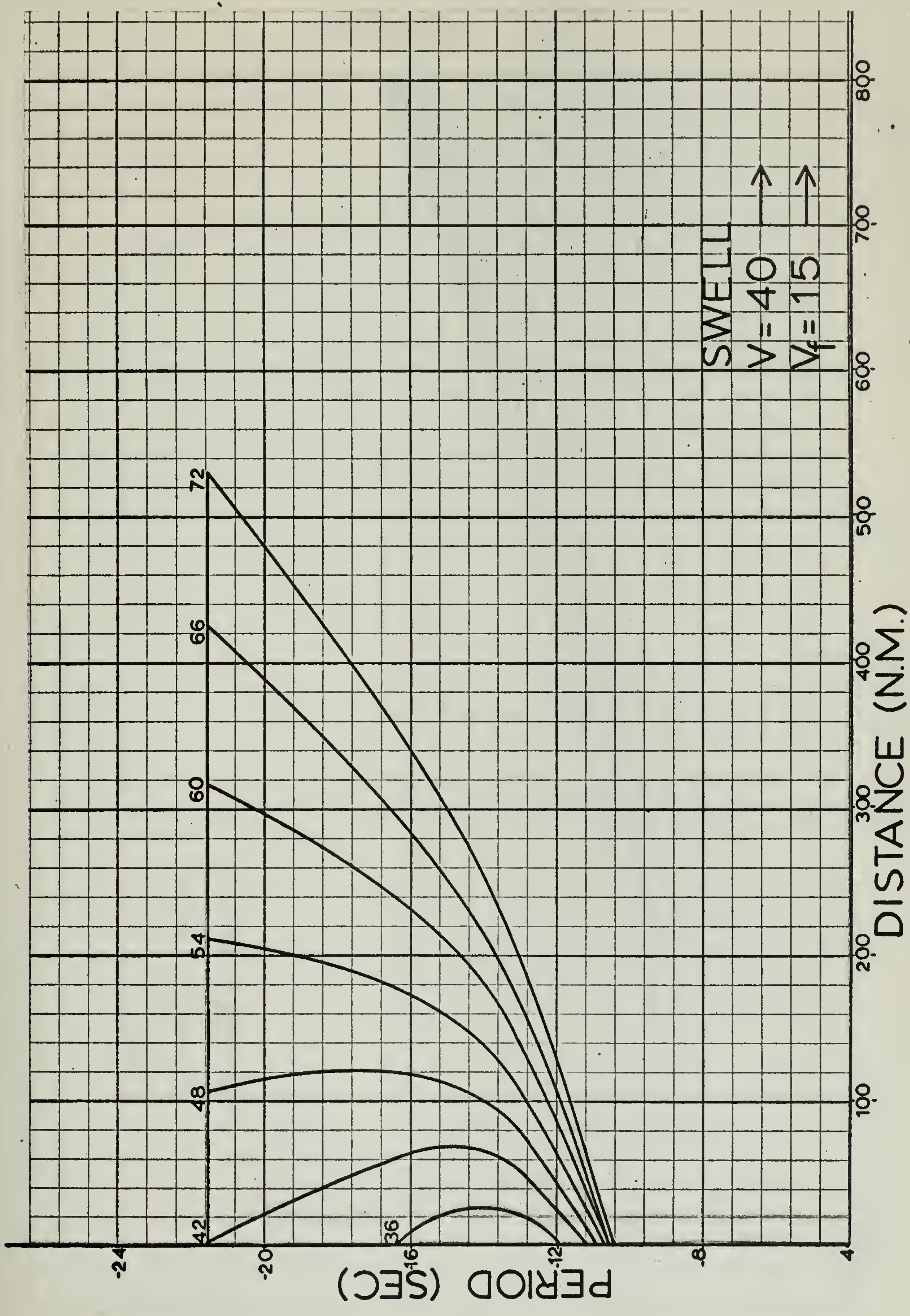
PERIOD (SEC)
DISTANCE (N.M.)
FOPRIME
V = 35
Vf = 35
36&>
30
24
18
12
6
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600

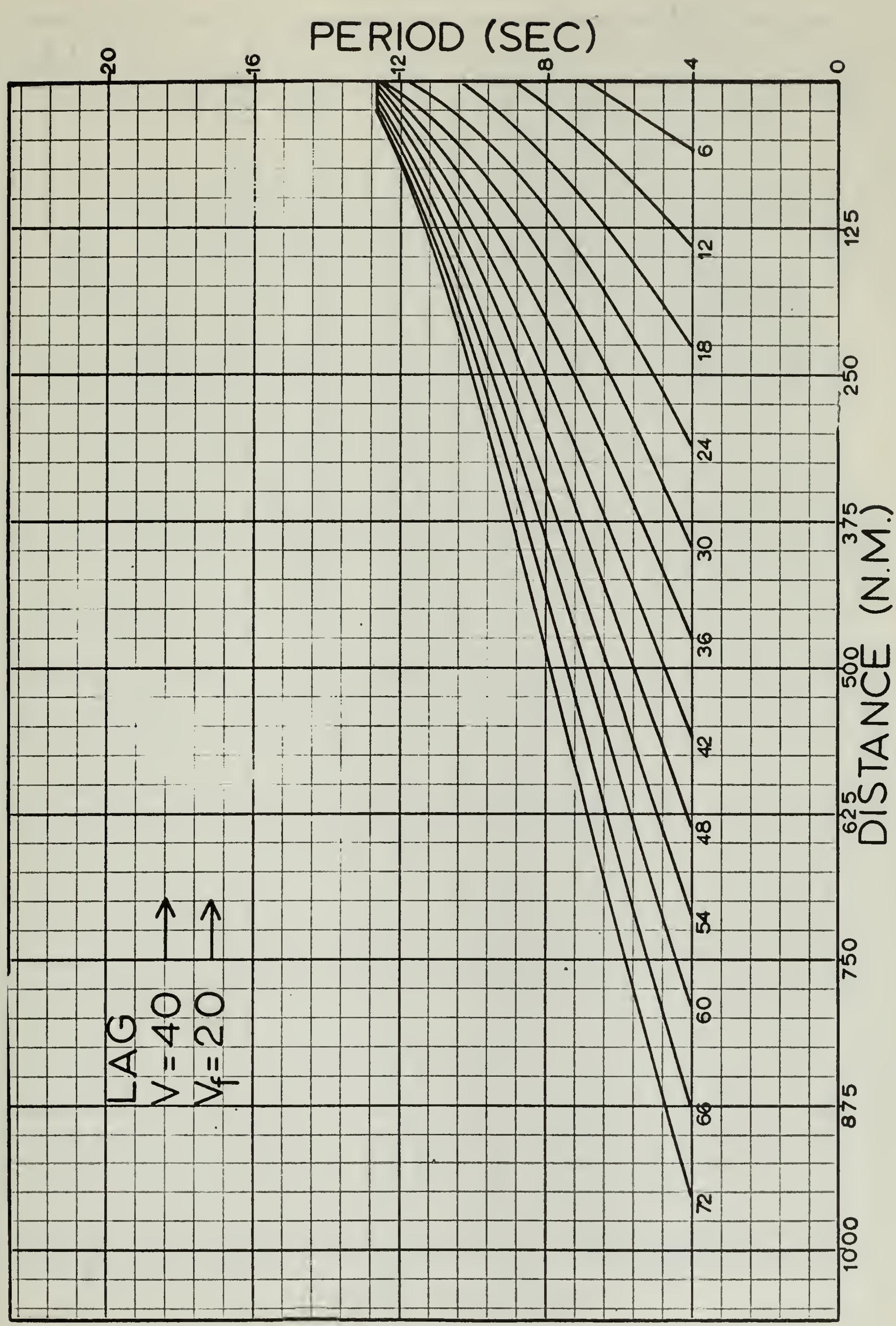

PERIOD (SEC)
20
16
12
8
4
0
100
200
300
400
500
600
700
800
DISTANCE (N.M.)
SUMDEL
V = 35
$V_f$ = 35
36
30
24
18
12
6


PERIOD (SEC)
20
16
12
8
4
0
75
150
225
300
375
450
525
600
DISTANCE (N.M.)
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 40
Vf = 15

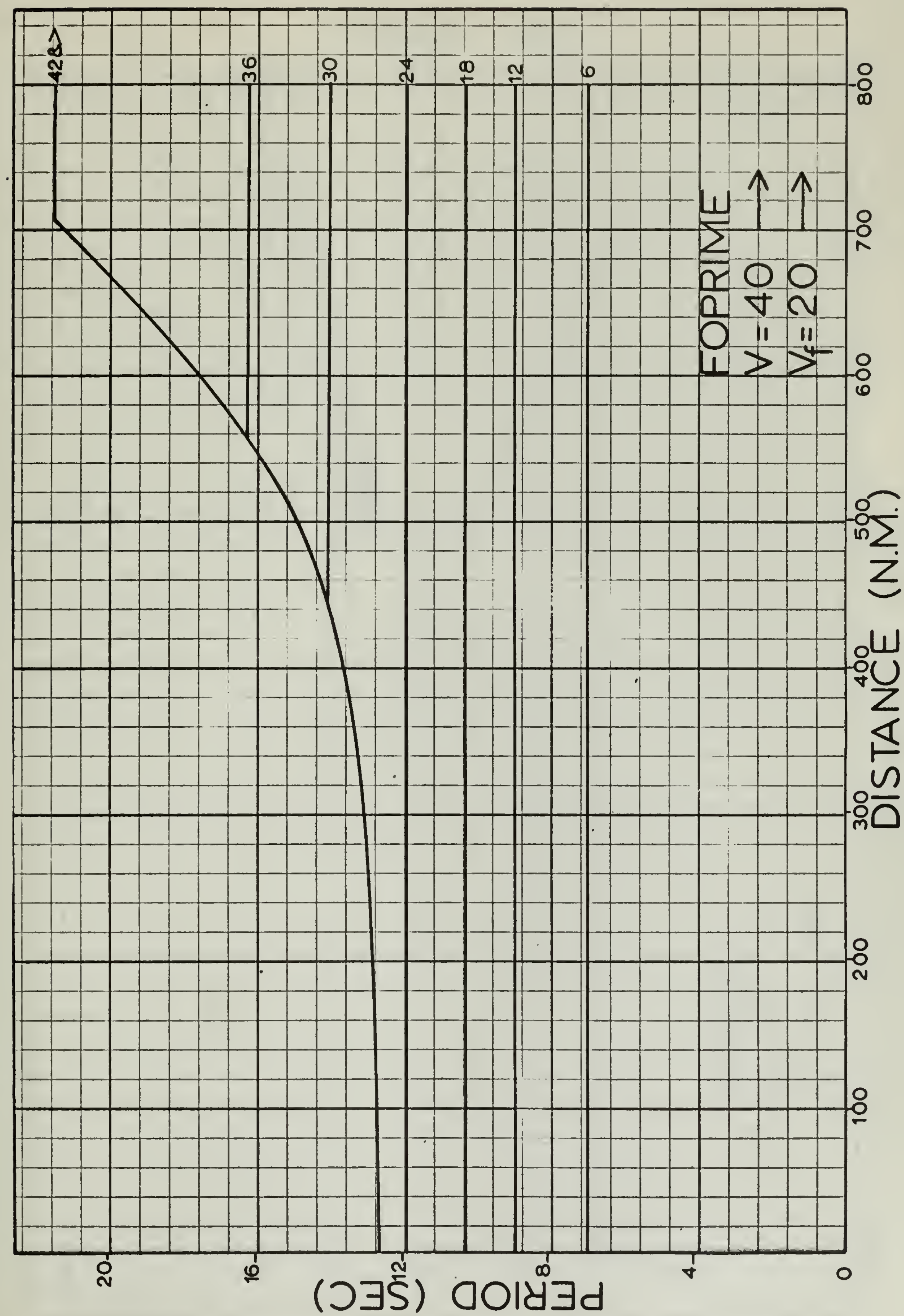

FOPRIME
V=40 ⟶
V=15 ⟶
DISTANCE (N.M.)
PERIOD (SEC)
0
4
8
12
16
20
100
200
300
400
500
600
700
800
6
12
18
24
30
36
42&>


PERIOD (SEC)
DISTANCE (N.M.)
SUMDEL
V = 40
Vf = 15
20
16
12
8
4
0
50
100
150
200
250
300
350
400
36
72
428
36
30
24
18
12
6

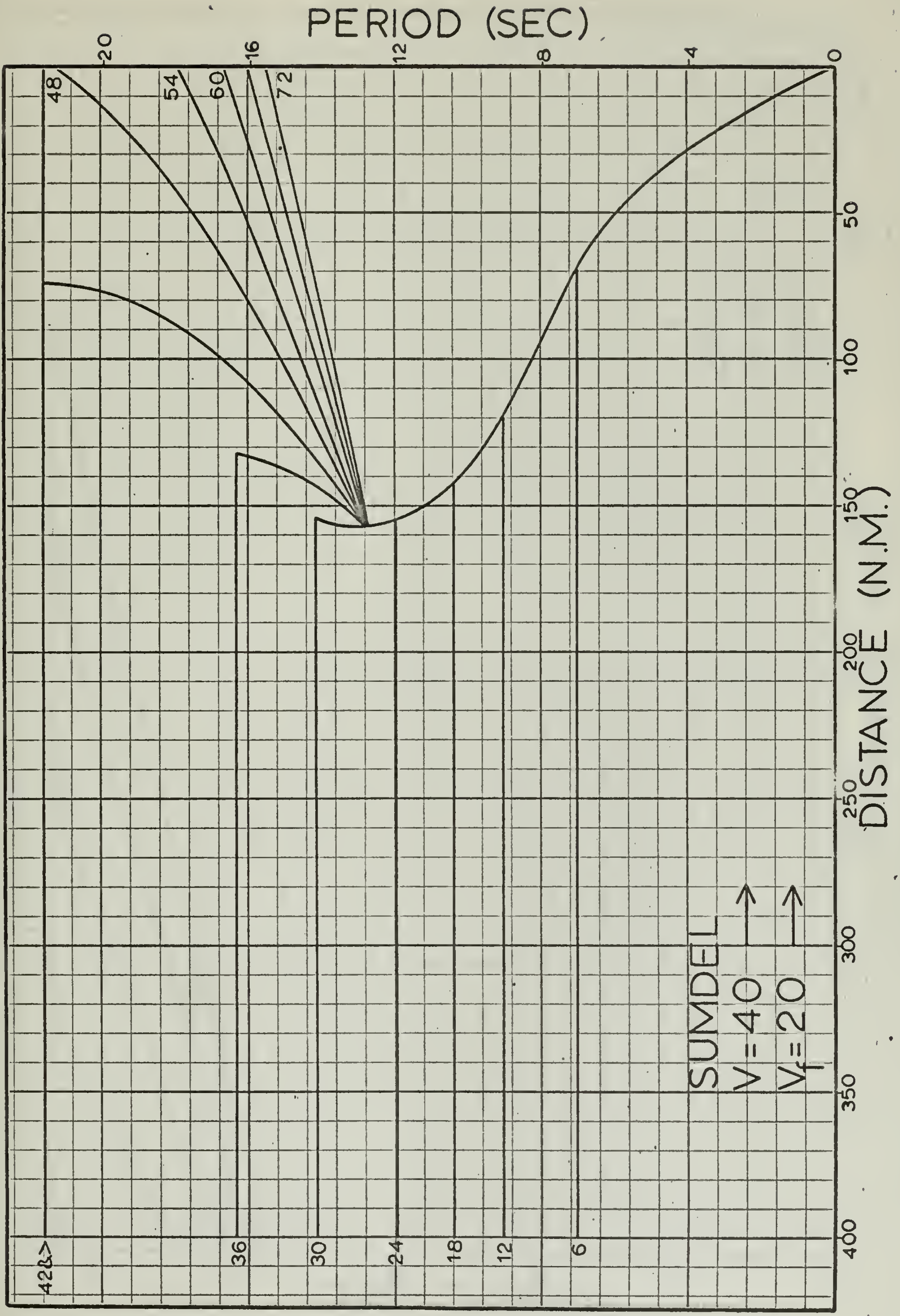

SWELL
V = 40
$V_f$ = 15
DISTANCE (N.M.)
PERIOD (SEC)
100
200
300
400
500
600
700
800
4
8
12
16
20
24
36
42
48
54
60
66
72

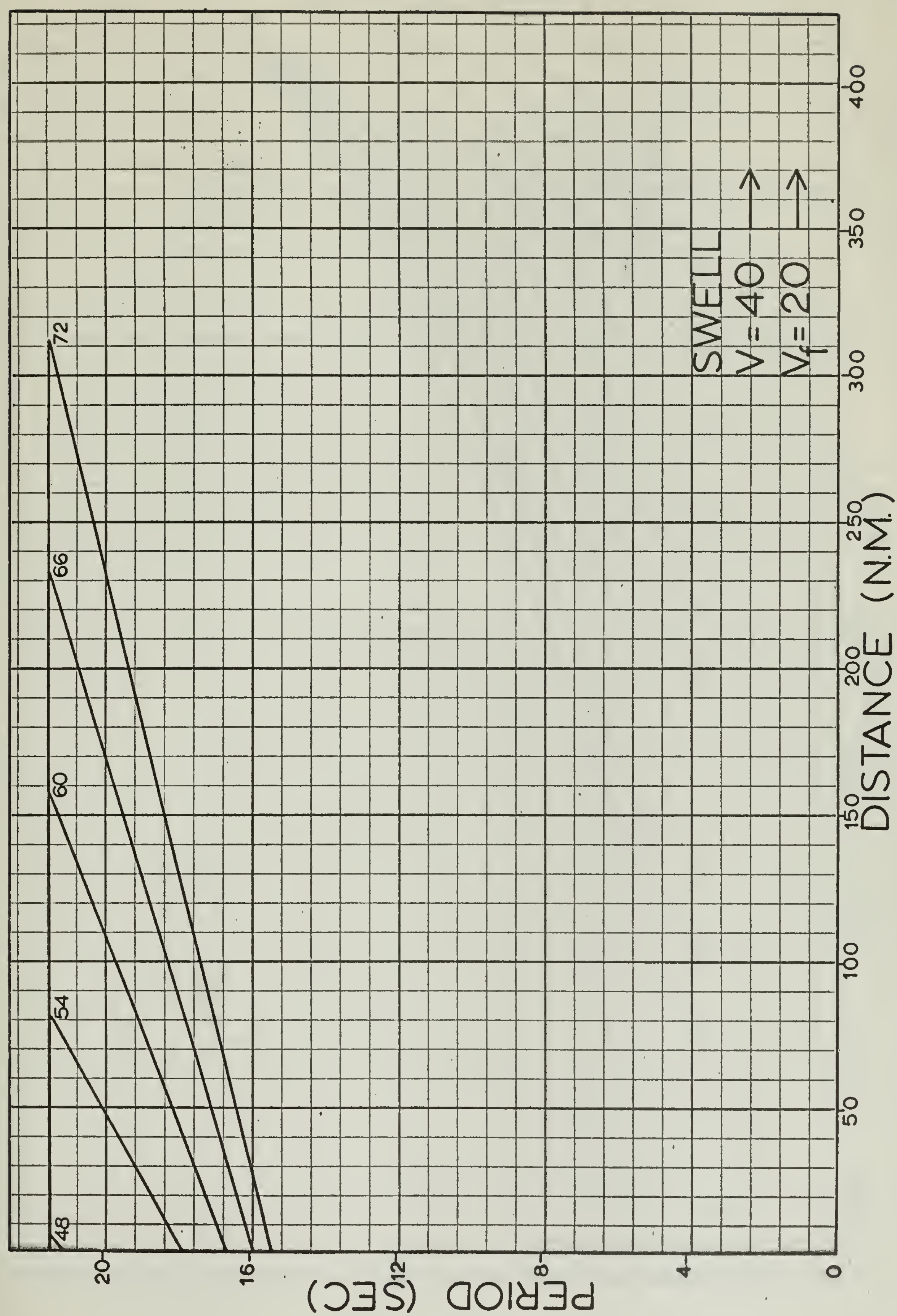


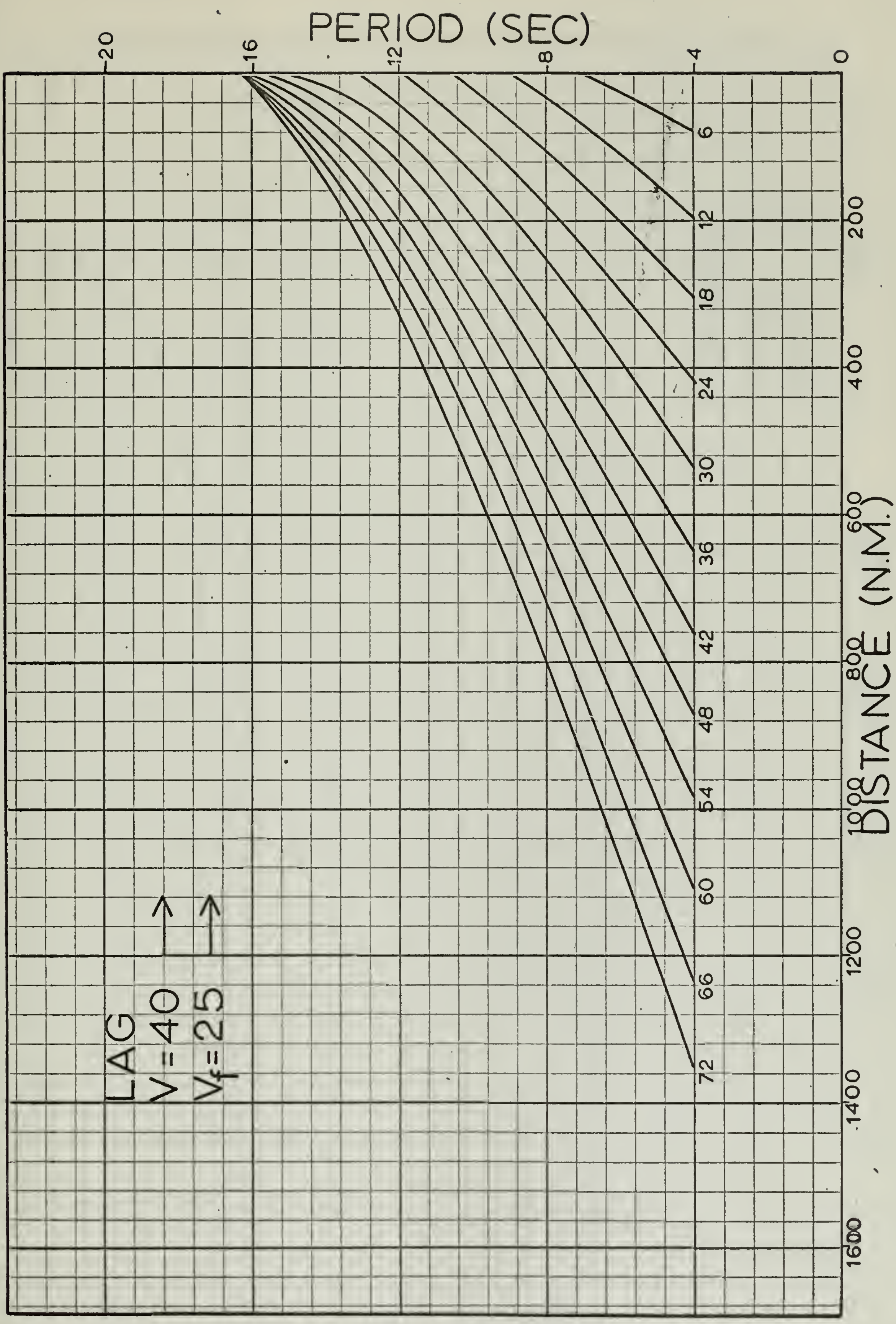
PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
125
250
375
500
625
750
875
1000
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 40
V_f = 20

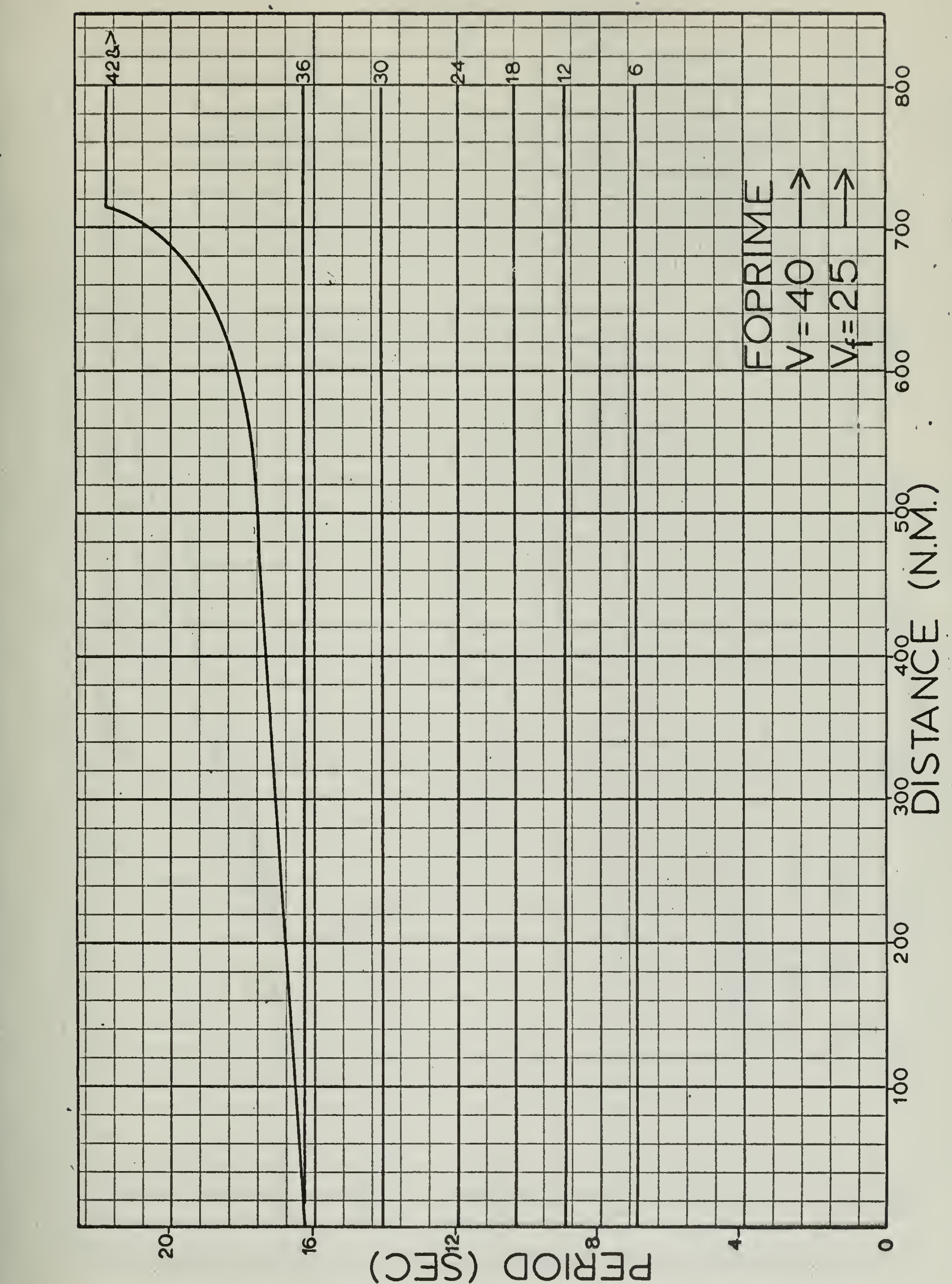


FOPRIME
V = 40
V_f = 20
42
36
30
24
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
100
200
300
400
500
600
700
800


PERIOD (SEC)
DISTANCE (N.M.)
SUMDEL
V = 40
$V_f$ = 20
48
54
60
72
42&>
36
30
24
18
12
6
20
16
12
8
4
0
50
100
150
200
250
300
350
400


SWELL
V = 40 →
$V_f$ = 20 →
48
54
60
66
72
DISTANCE (N.M.)
50
100
150
200
250
300
350
400
PERIOD (SEC)
0
4
8
12
16
20


PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 40
$V_f$ = 25


FOPRIME
V = 40
V_f = 25
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
100
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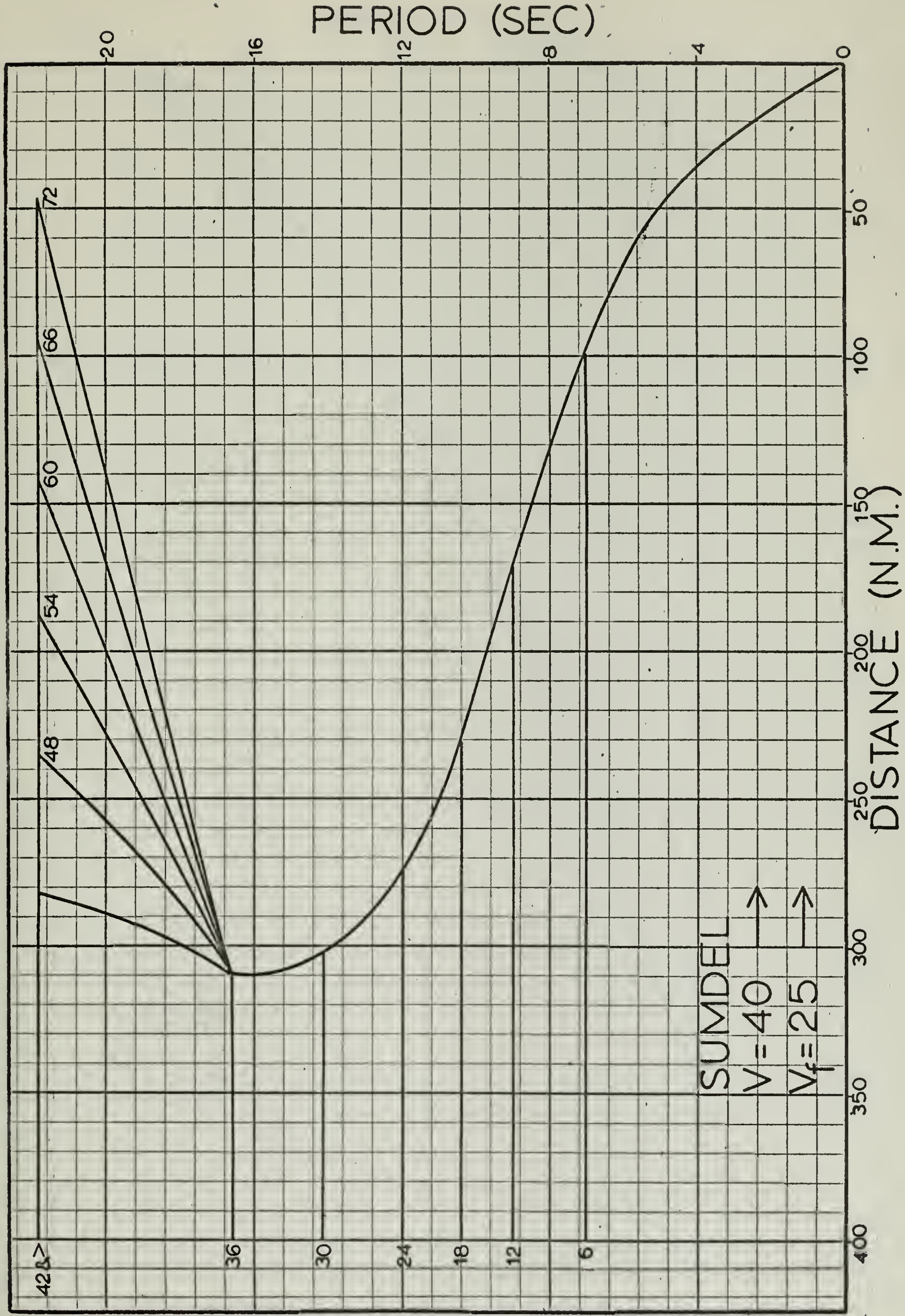
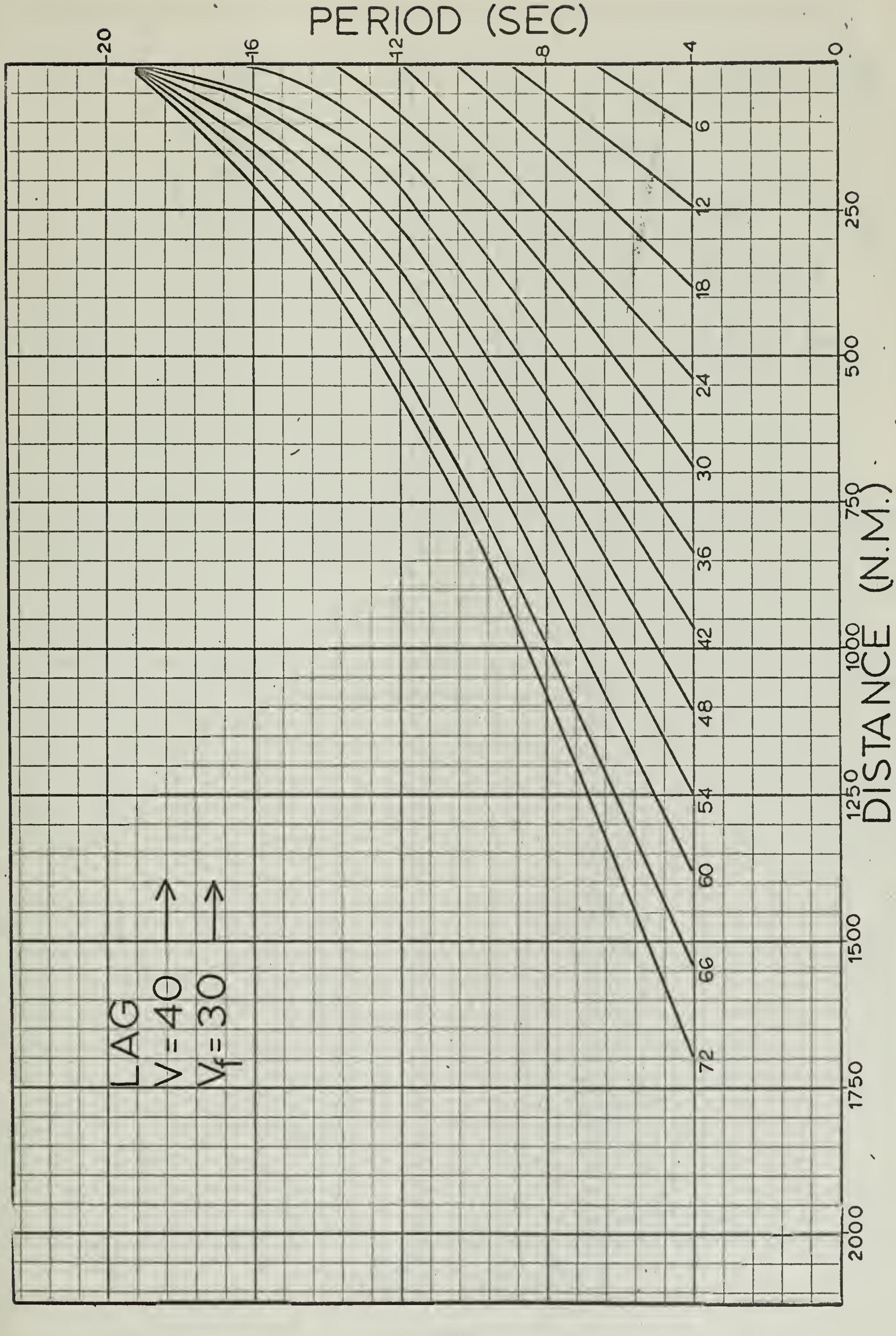
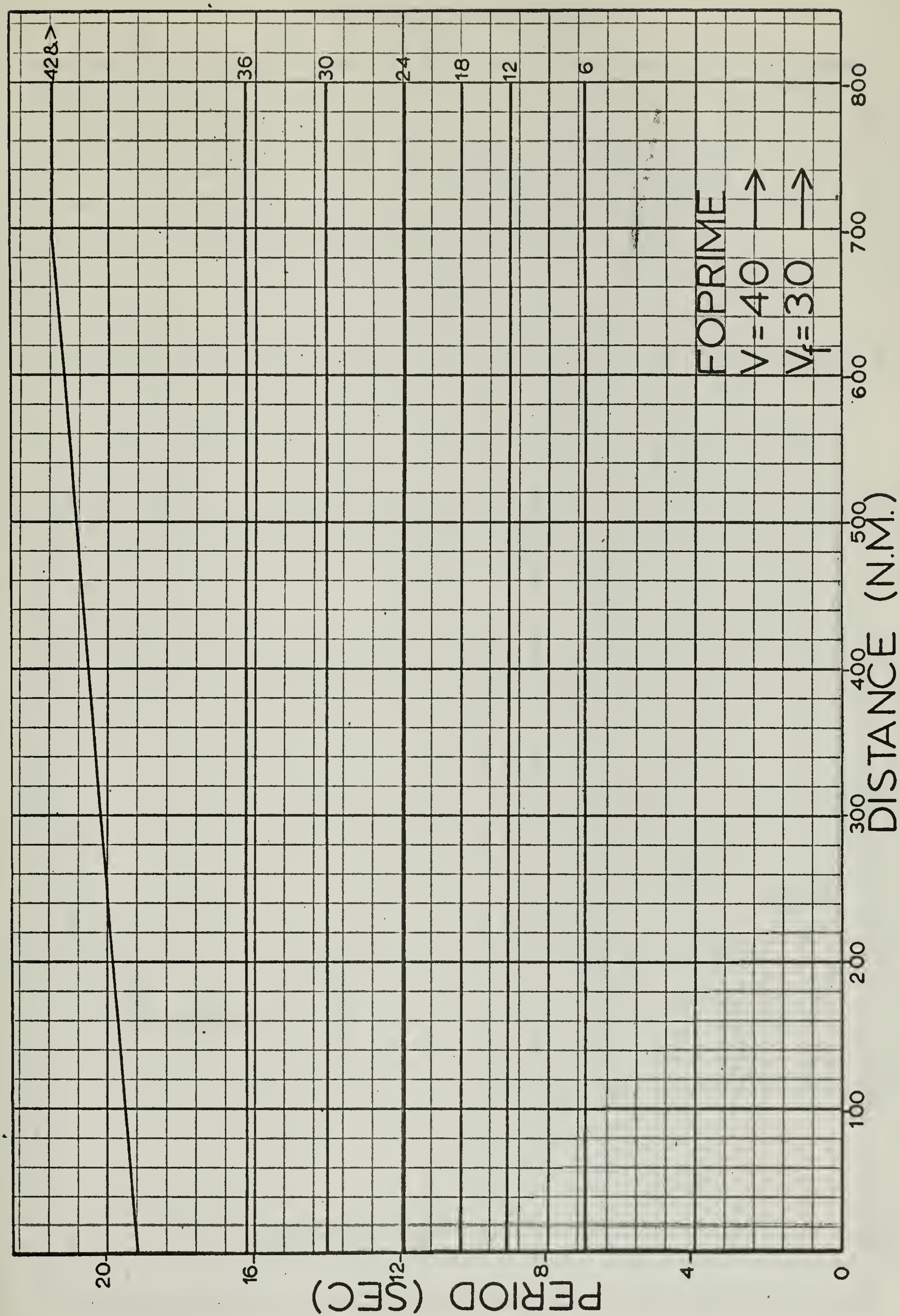
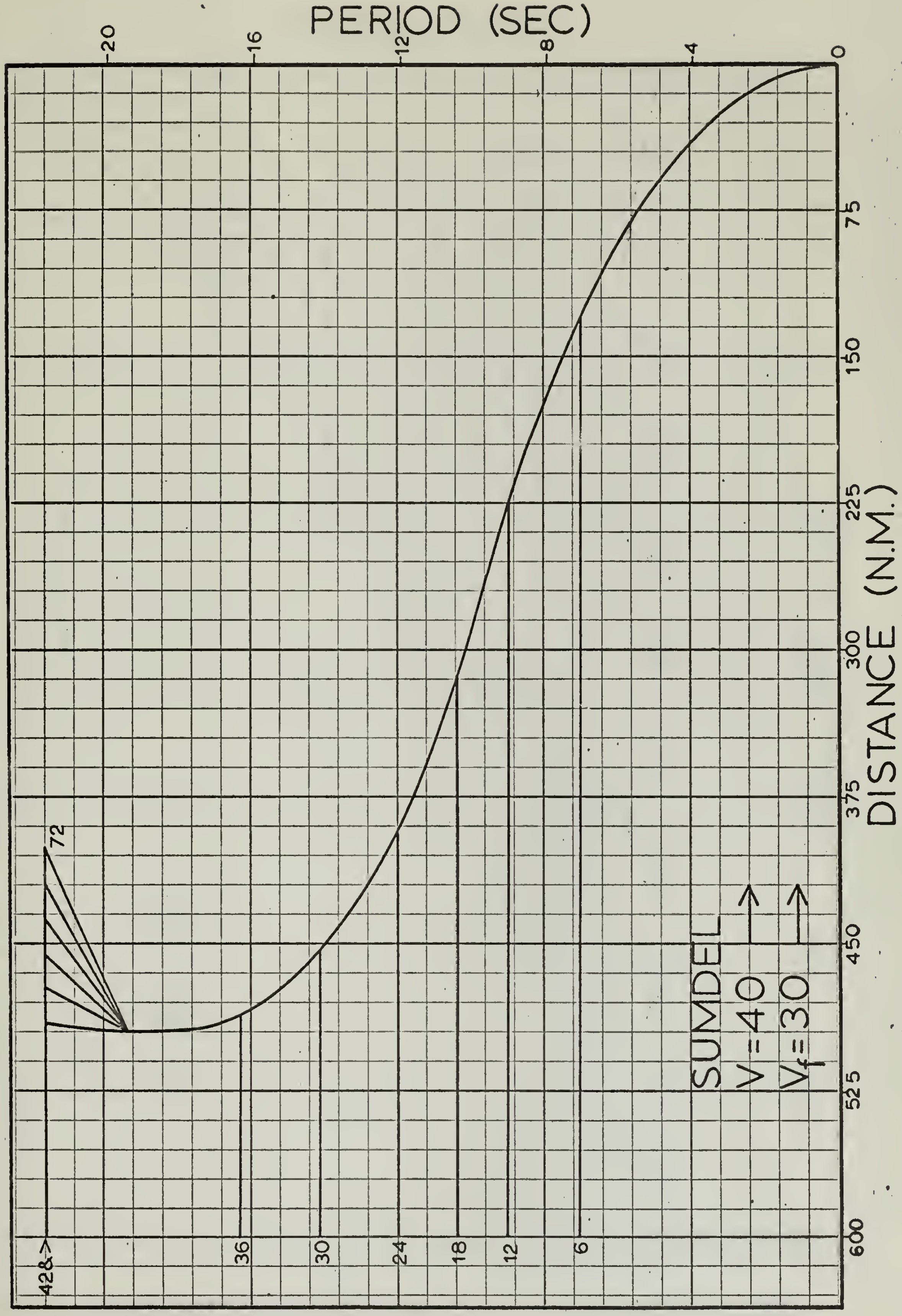
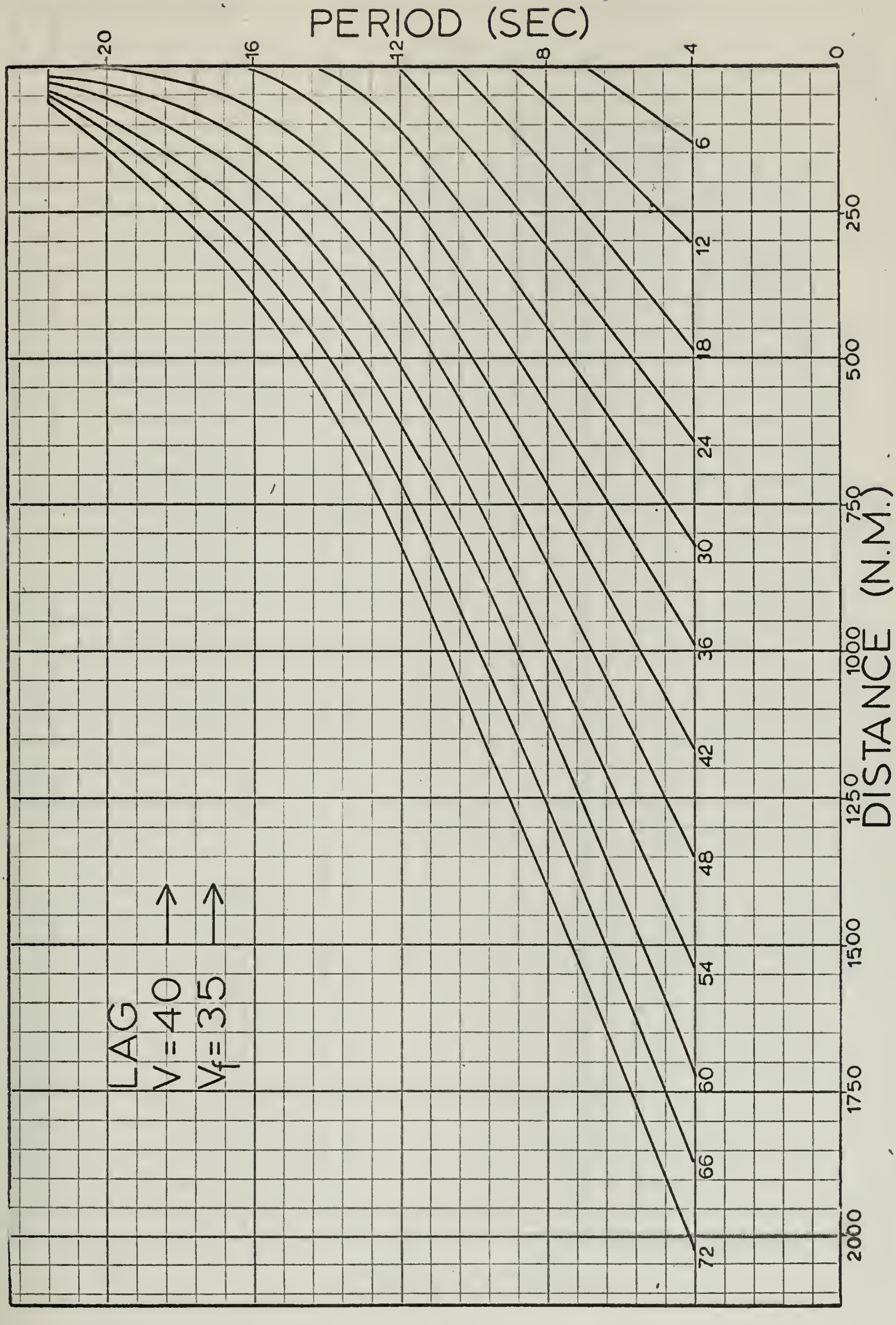
12
18
24
30
36
42

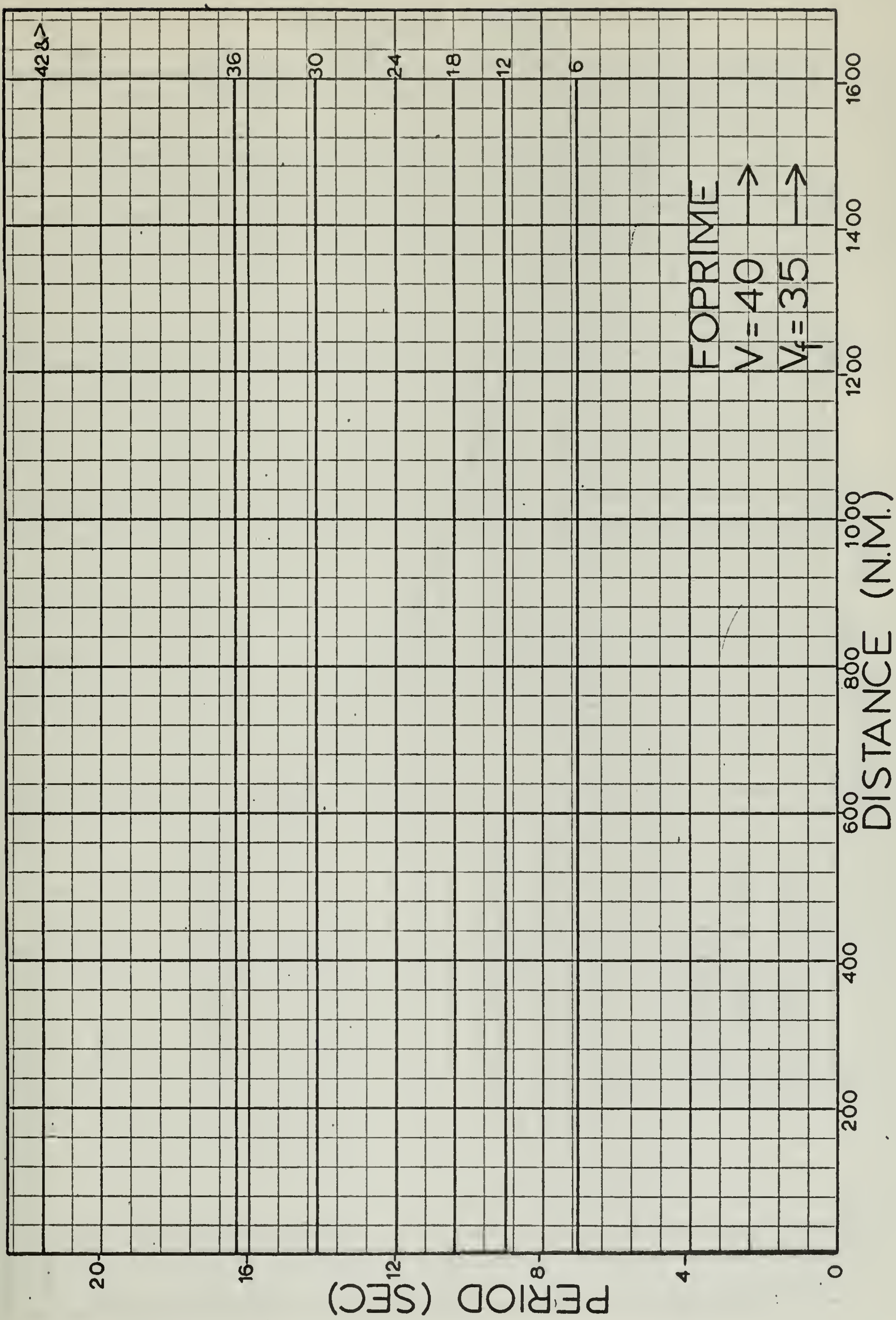

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
50
100
150
200
250
300
350
400
72
66
60
54
48
42 &>
36
30
24
18
12
6
SUMDEL
V = 40
$V_f$ = 25

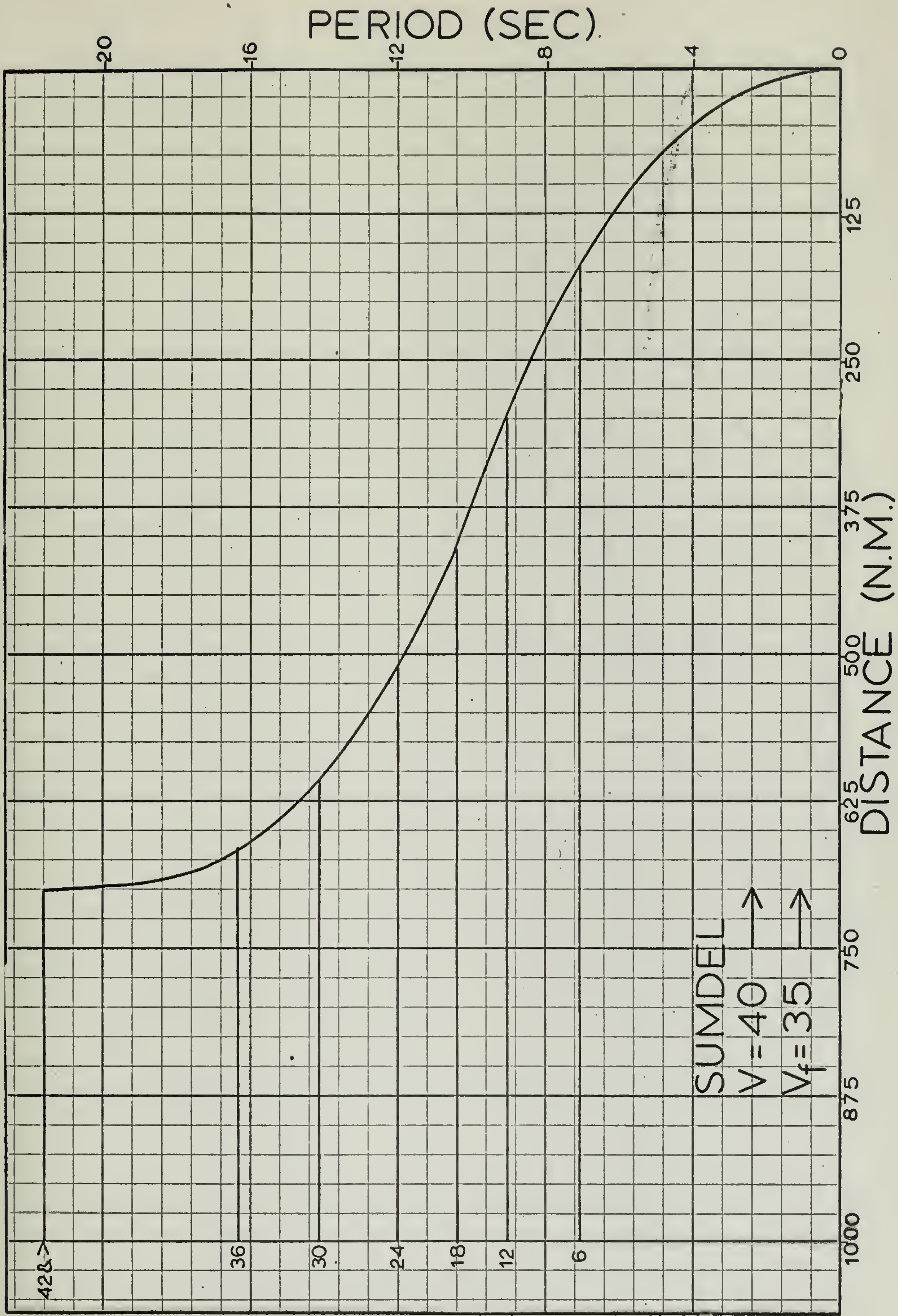

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
250
500
750
1000
1250
1500
1750
2000
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 40
V_f = 30

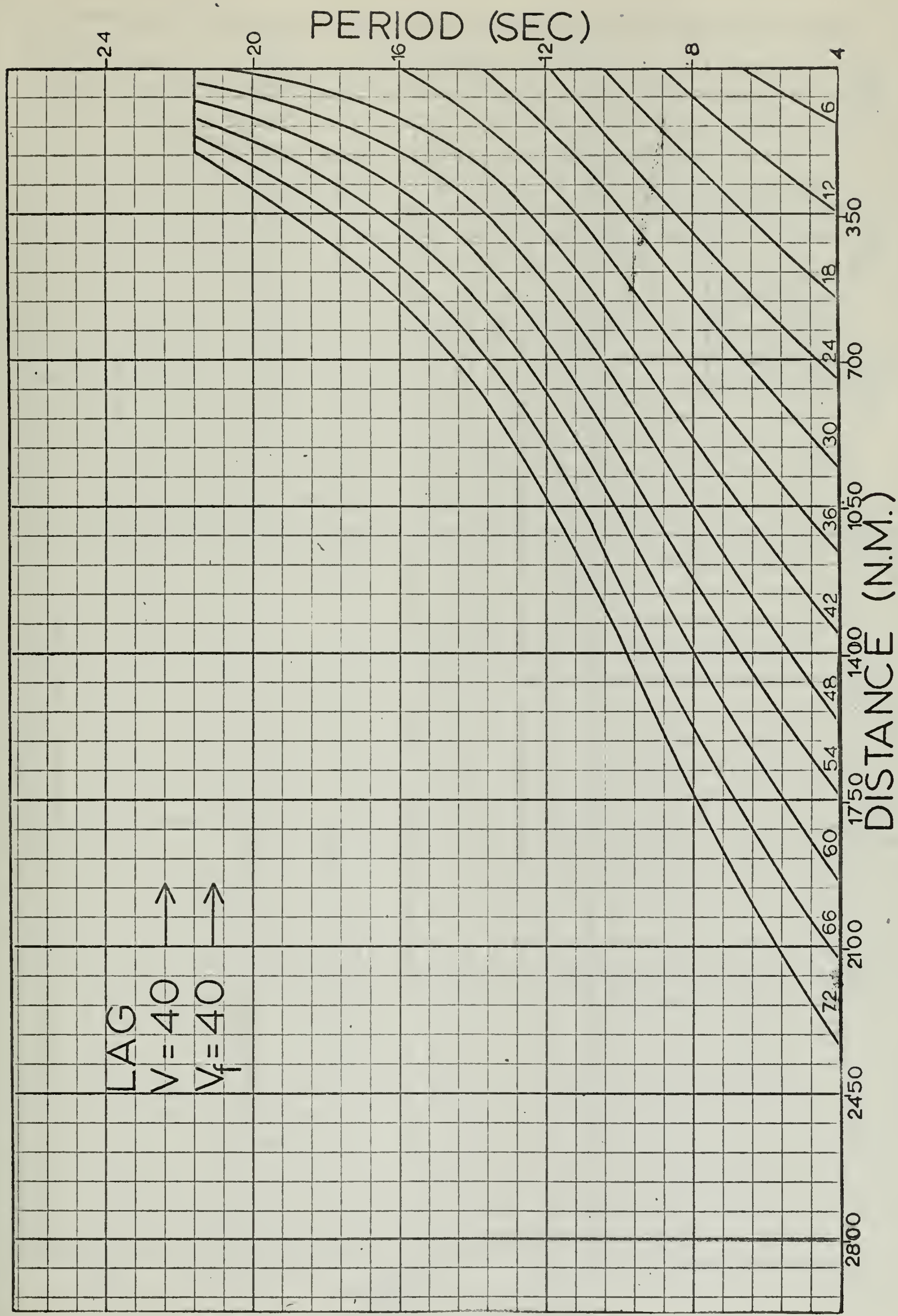

FOPRIME
V = 40
Vf = 30
42&>
36
30
24
18
12
6
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
100
200
300
400
500
600
700
800


PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
75
150
225
300
375
450
525
600
SUMDEL
V = 40
Vf = 30
72
428->
36
30
24
18
12
6

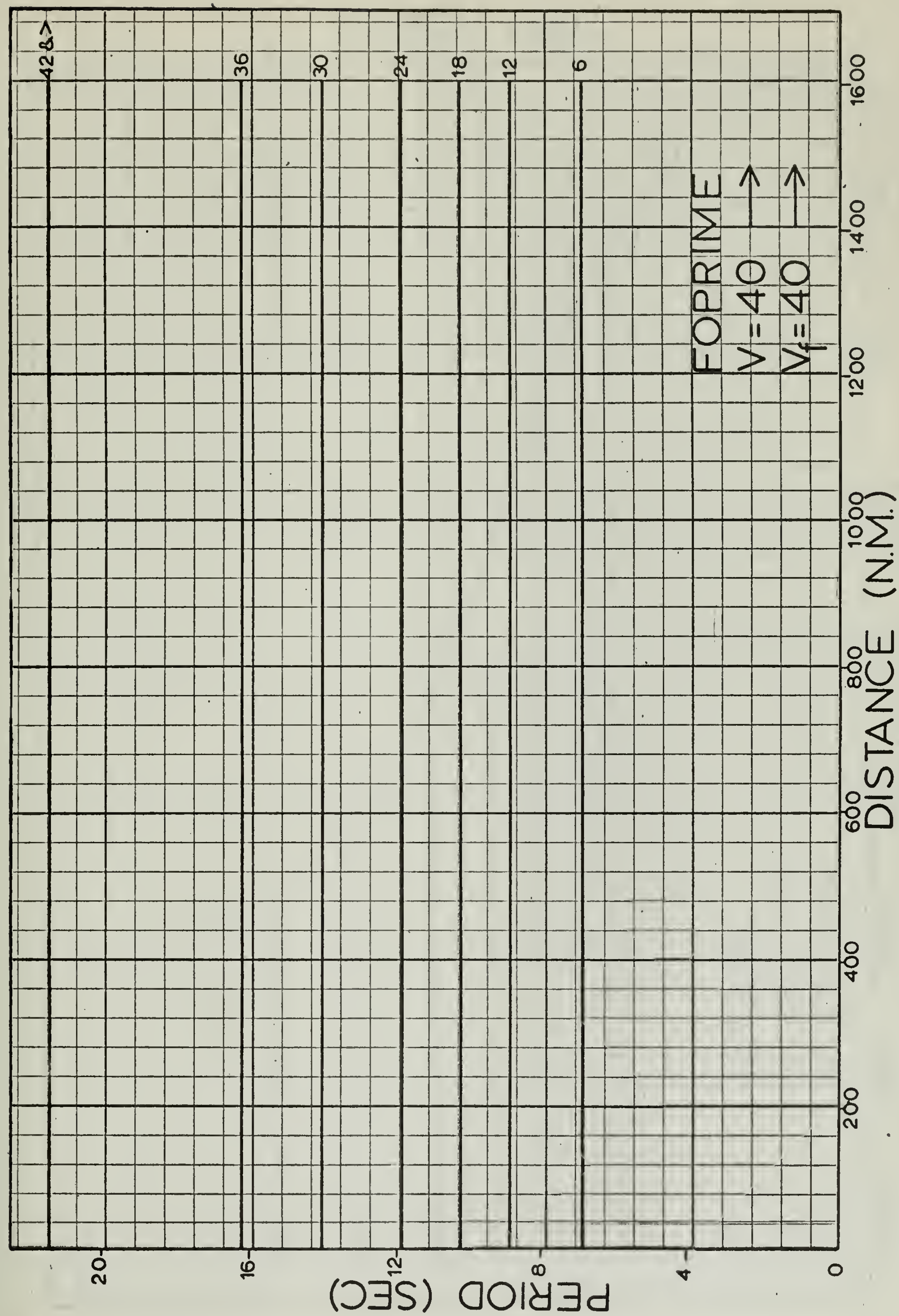

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
250
500
750
1000
1250
1500
1750
2000
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 40
$V_f$ = 35


FOPRIME
V = 40
$V_f$ = 35
42 &
36
30
24
18
12
6
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
PERIOD (SEC)
0
4
8
12
16
20


PERIOD (SEC)
20
16
12
8
4
0
125
250
375
500
625
750
875
1000
DISTANCE (N.M.)
SUMDEL
V = 40
$V_f$ = 35
428
36
30
24
18
12
6



PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
350
700
1050
1400
1750
2100
2450
2800
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 40
$V_f$ = 40



FOPRIME
V = 40
$V_f$ = 40
DISTANCE (N.M.)
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
6
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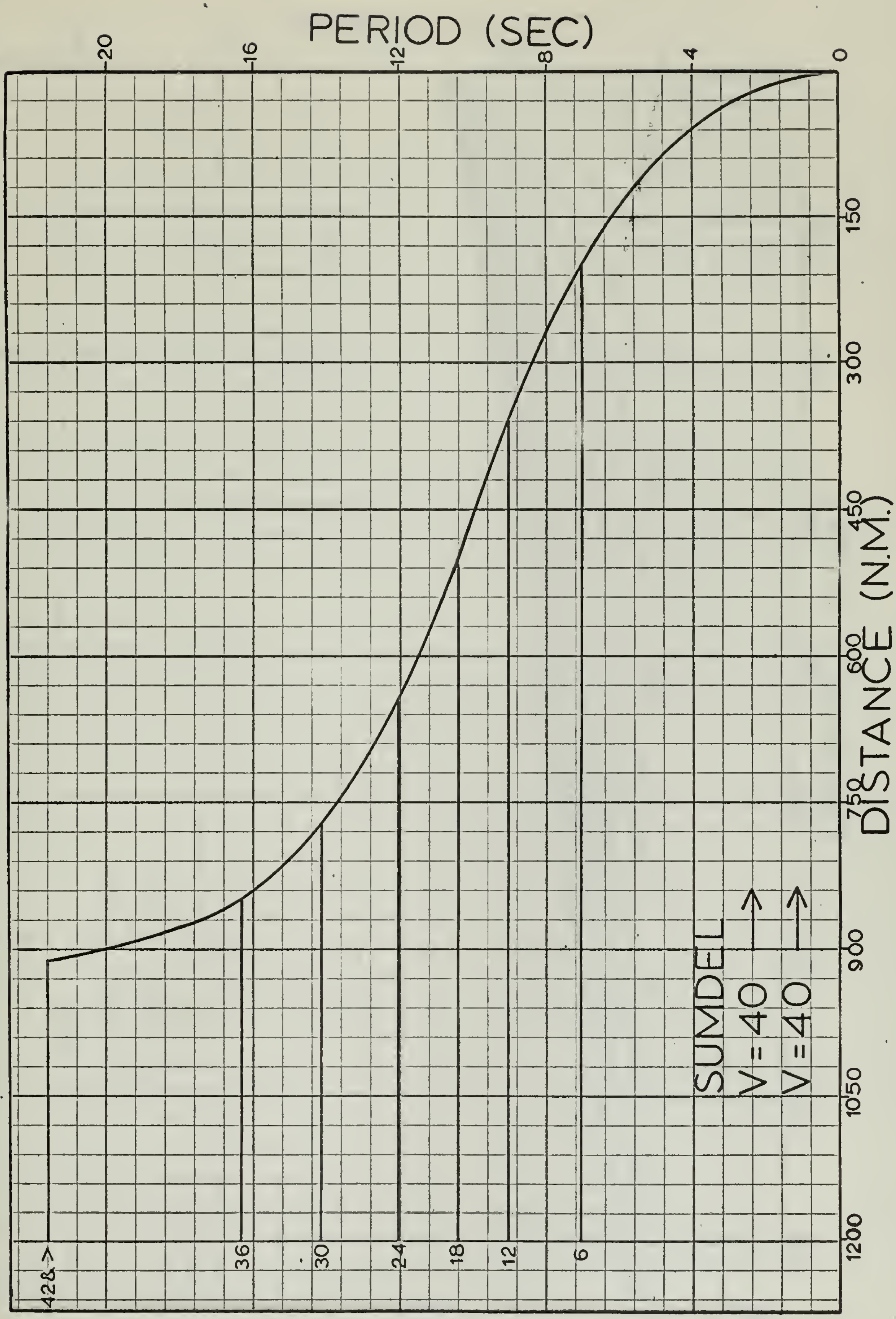
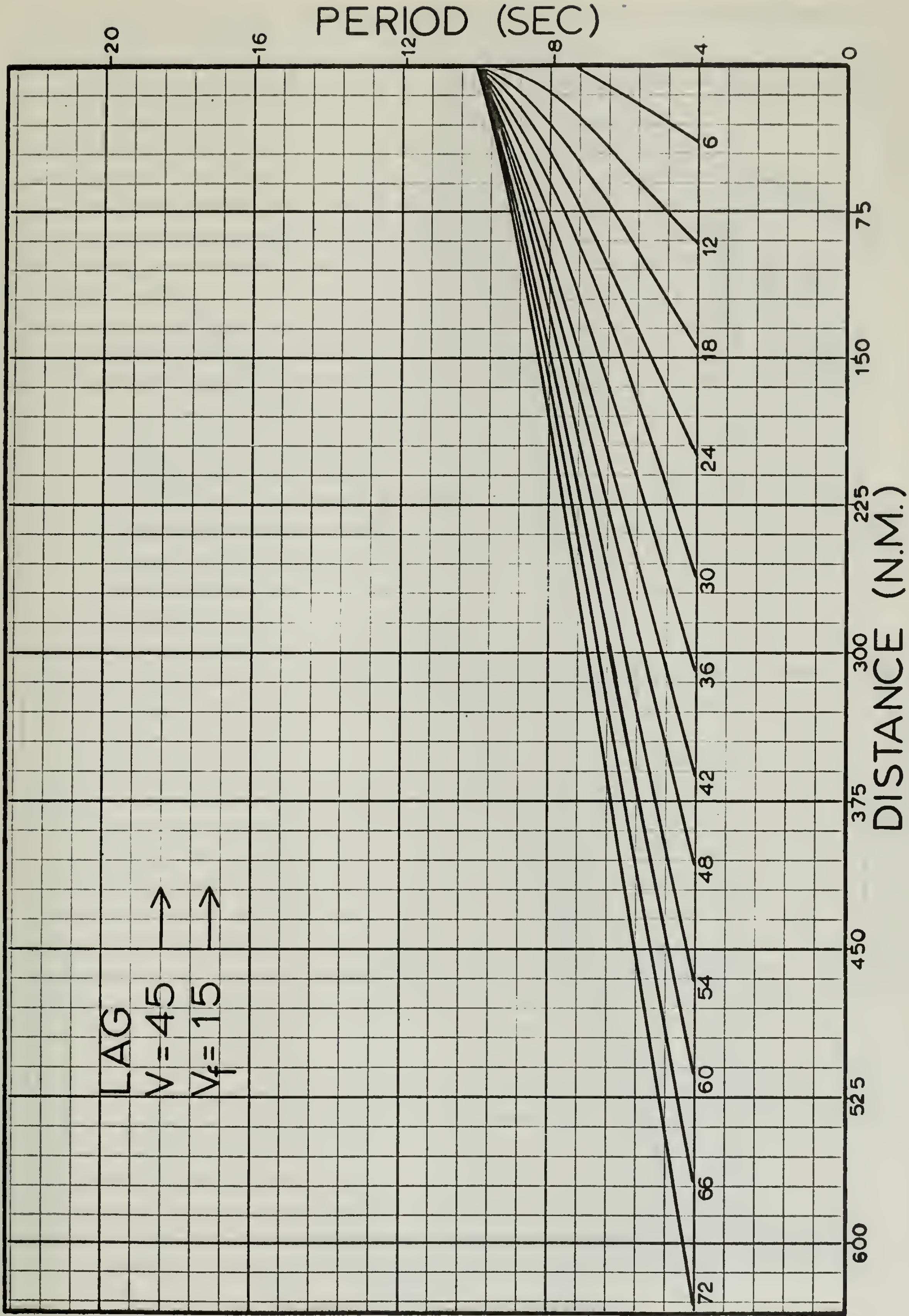
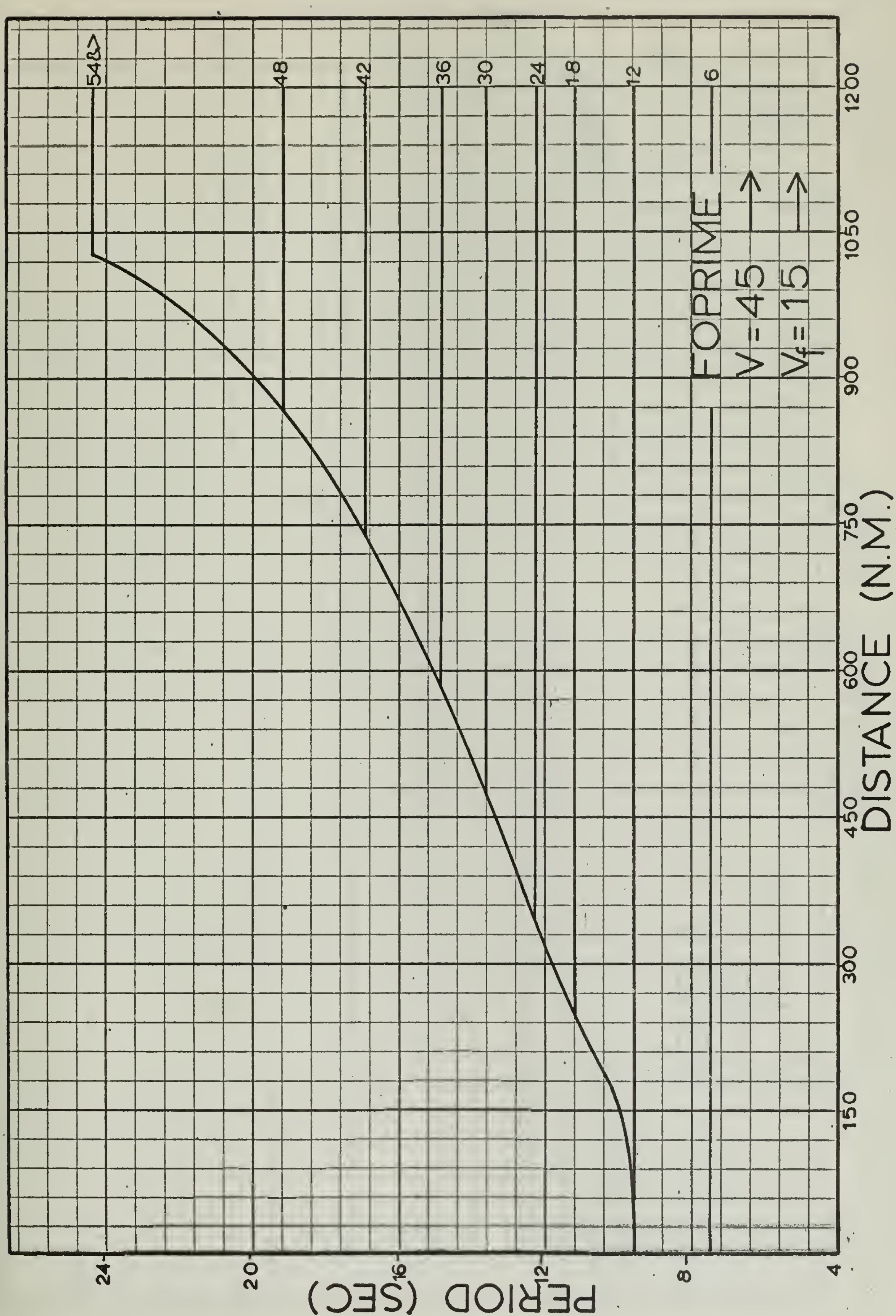
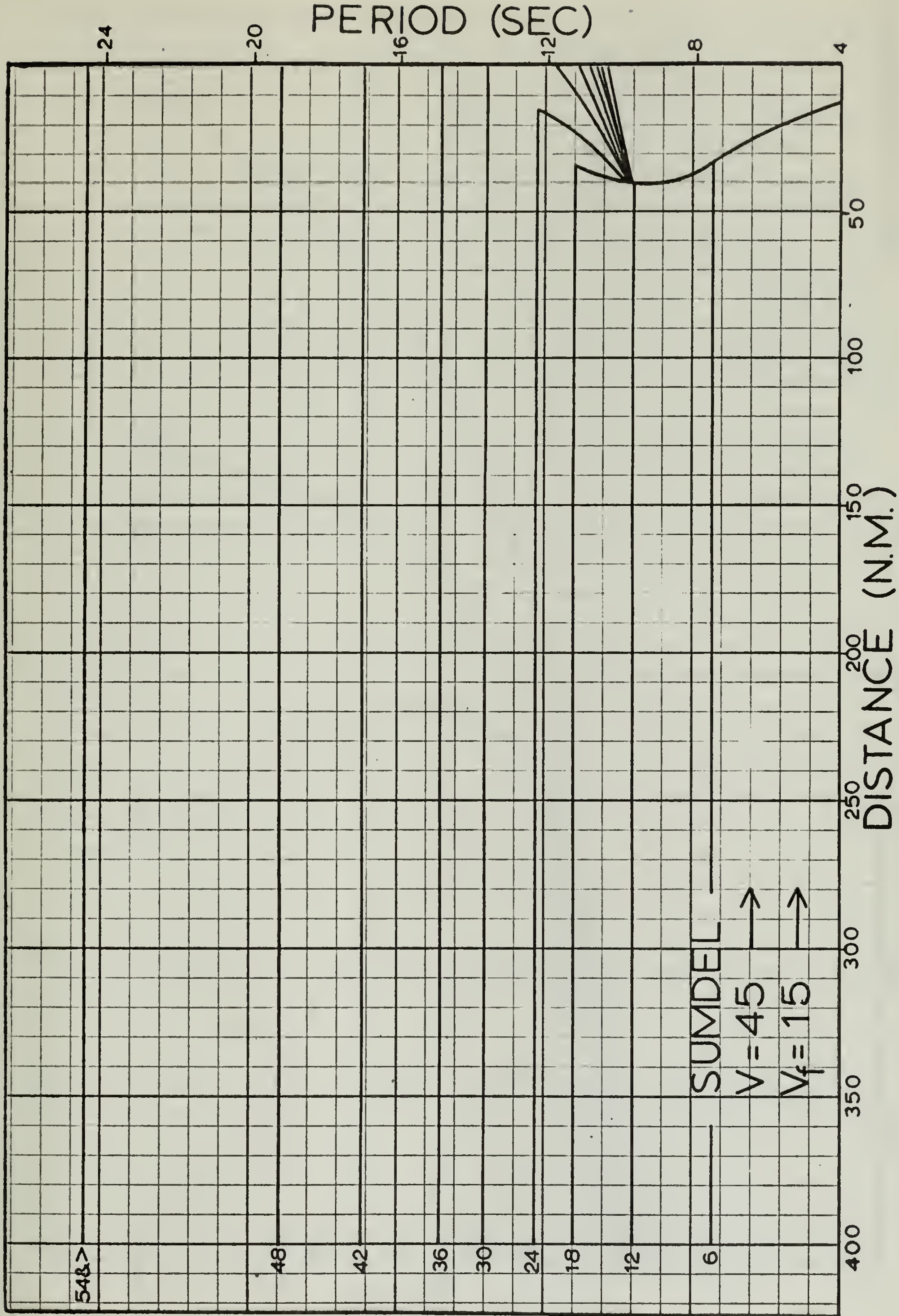
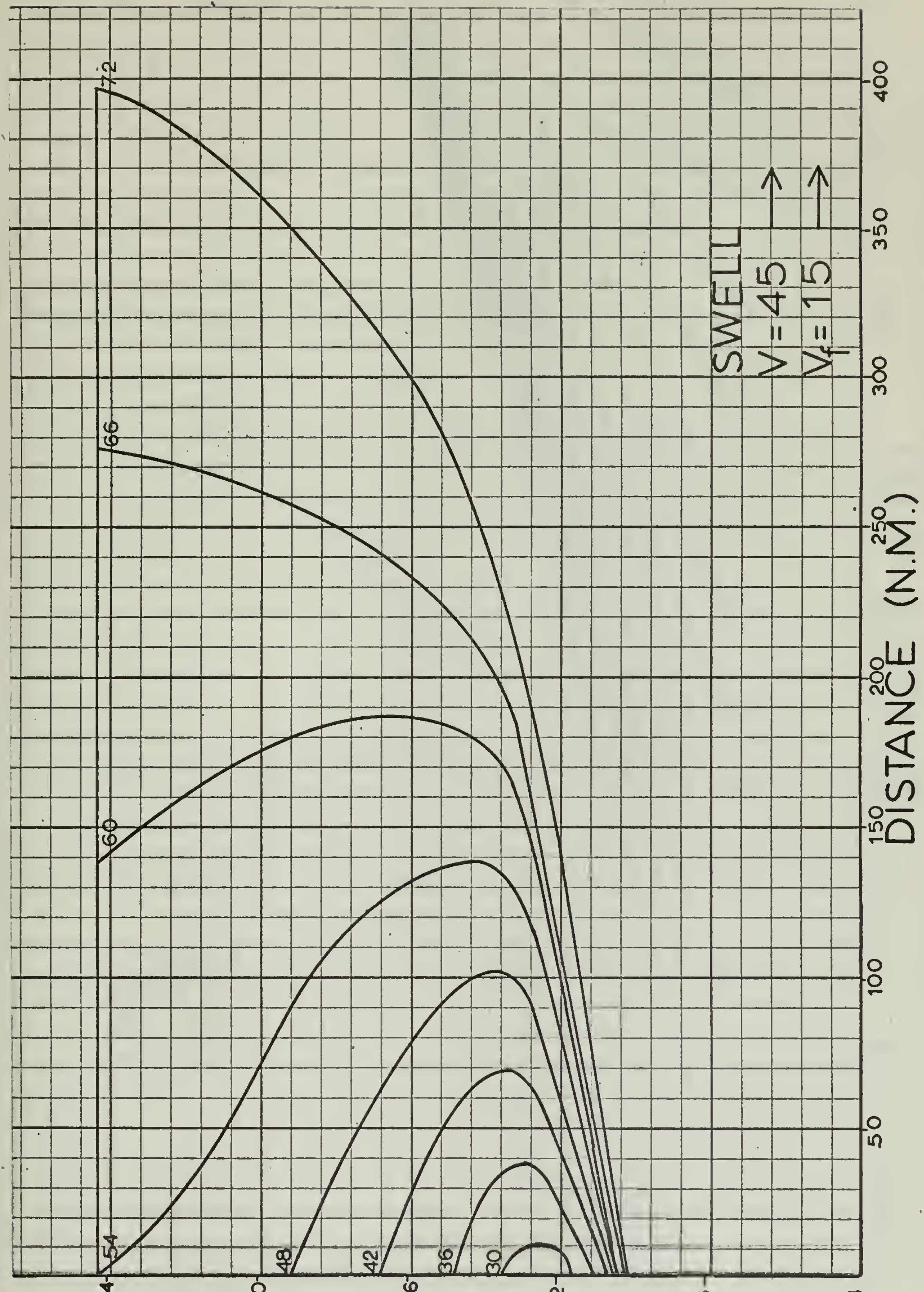
18
24
30
36
42 >

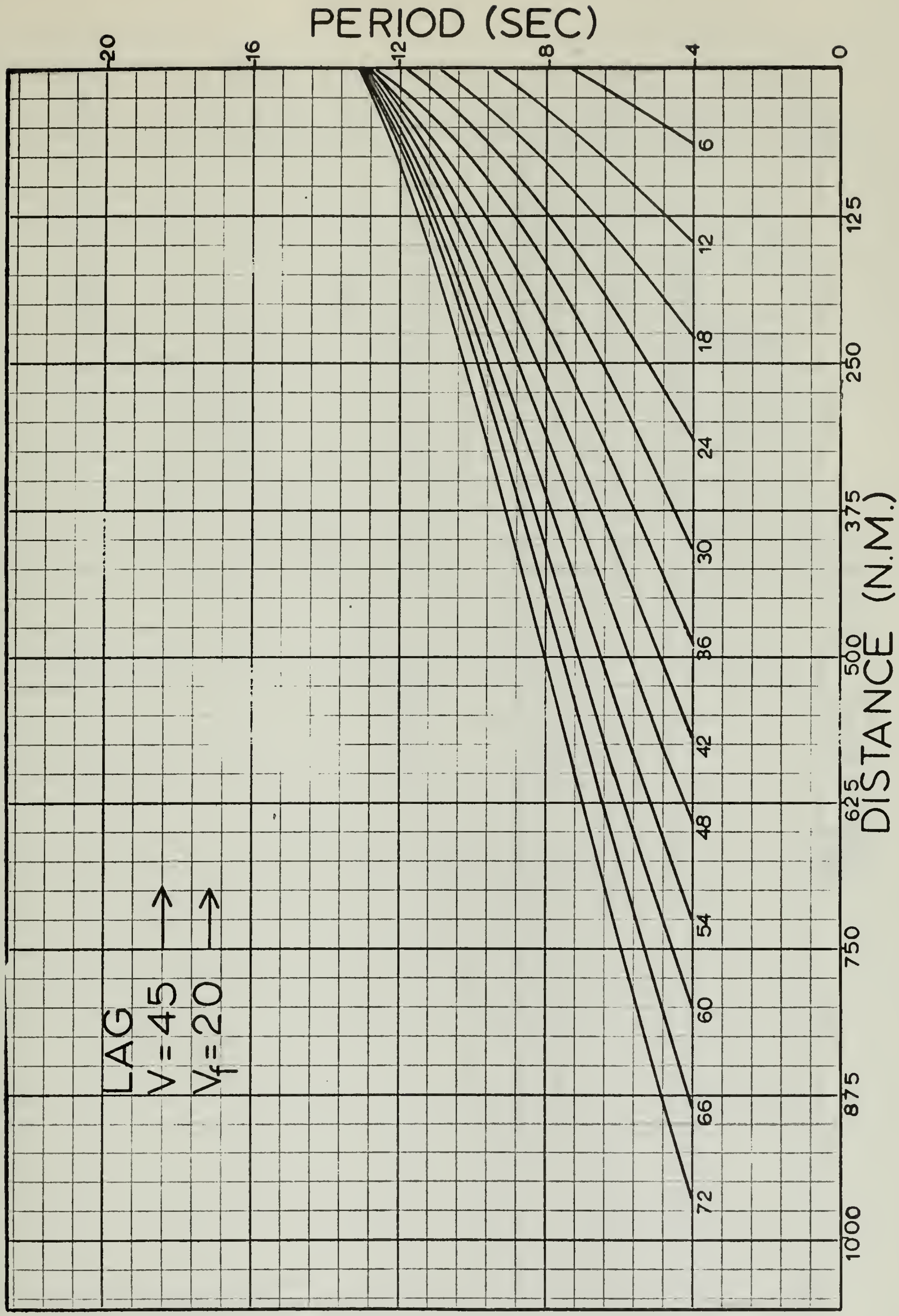

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
150
300
450
600
750
900
1050
1200
SUMDEL
V = 40
V = 40
42&->
36
30
24
18
12
6

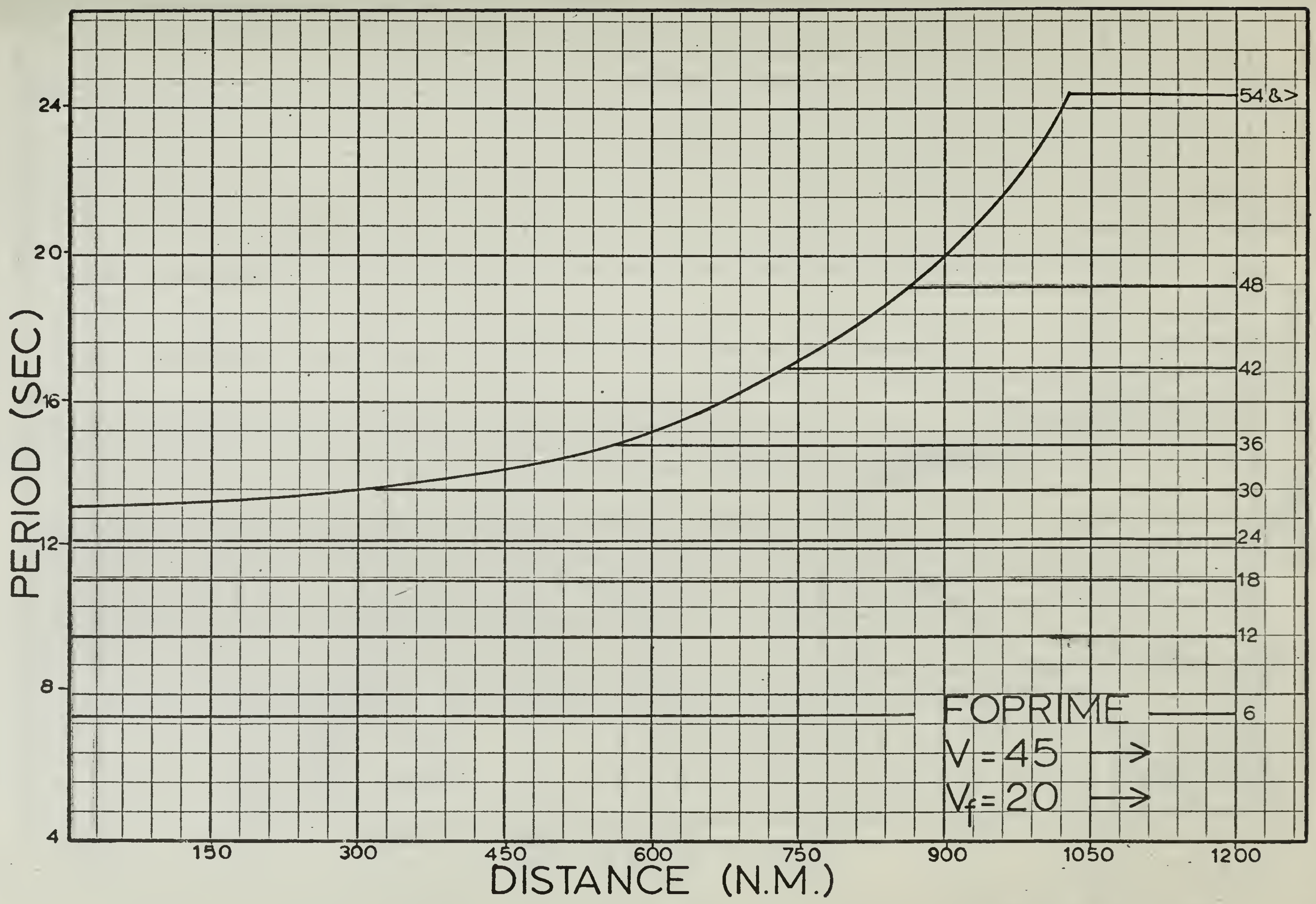

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
75
150
225
300
375
450
525
600
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 45
$V_f$ = 15

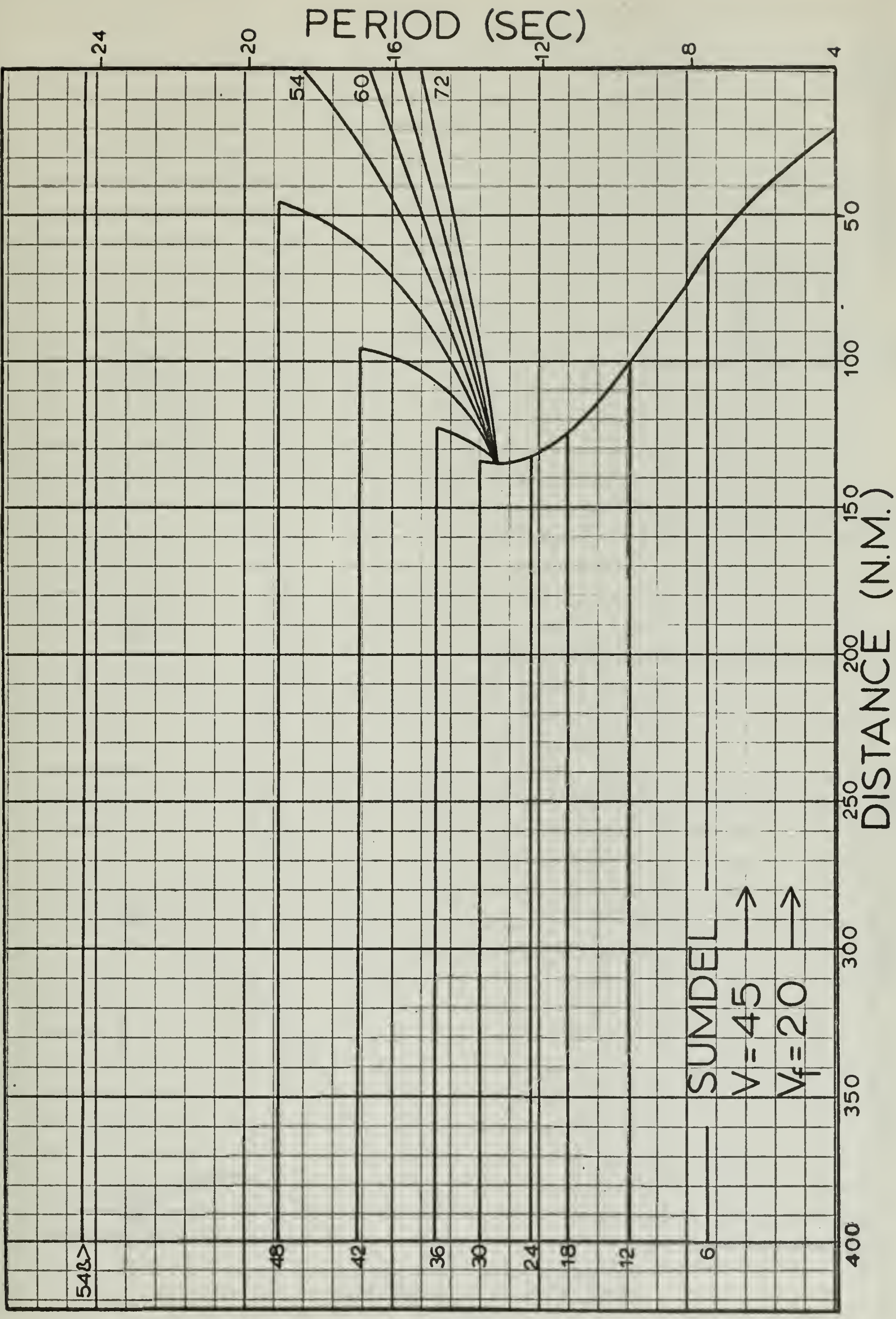

FOPRIME
V = 45
V_f = 15
DISTANCE (N.M.)
150
300
450
600
750
900
1050
1200
PERIOD (SEC)
4
8
12
16
20
24
54&>
48
42
36
30
24
18
12
6

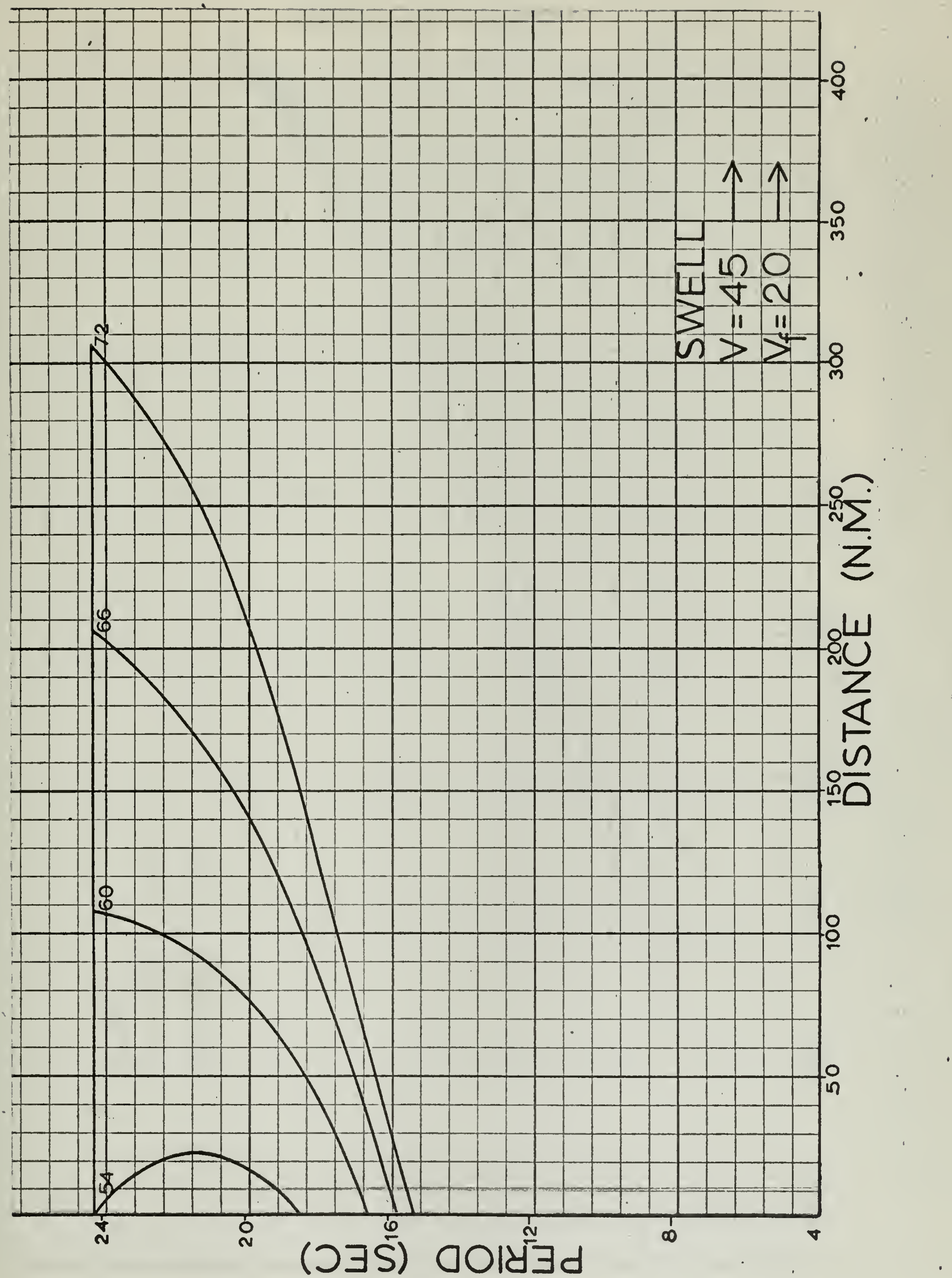

PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
50
100
150
200
250
300
350
400
SUMDEL
V = 45
Vf = 15
548>
48
42
36
30
24
18
12
6


SWELL
V = 45 →
$V_f$ = 15 →
DISTANCE (N.M.)
PERIOD (SEC)
50
100
150
200
250
300
350
400
4
8
12
16
20
24
30
36
42
48
54
60
66
72

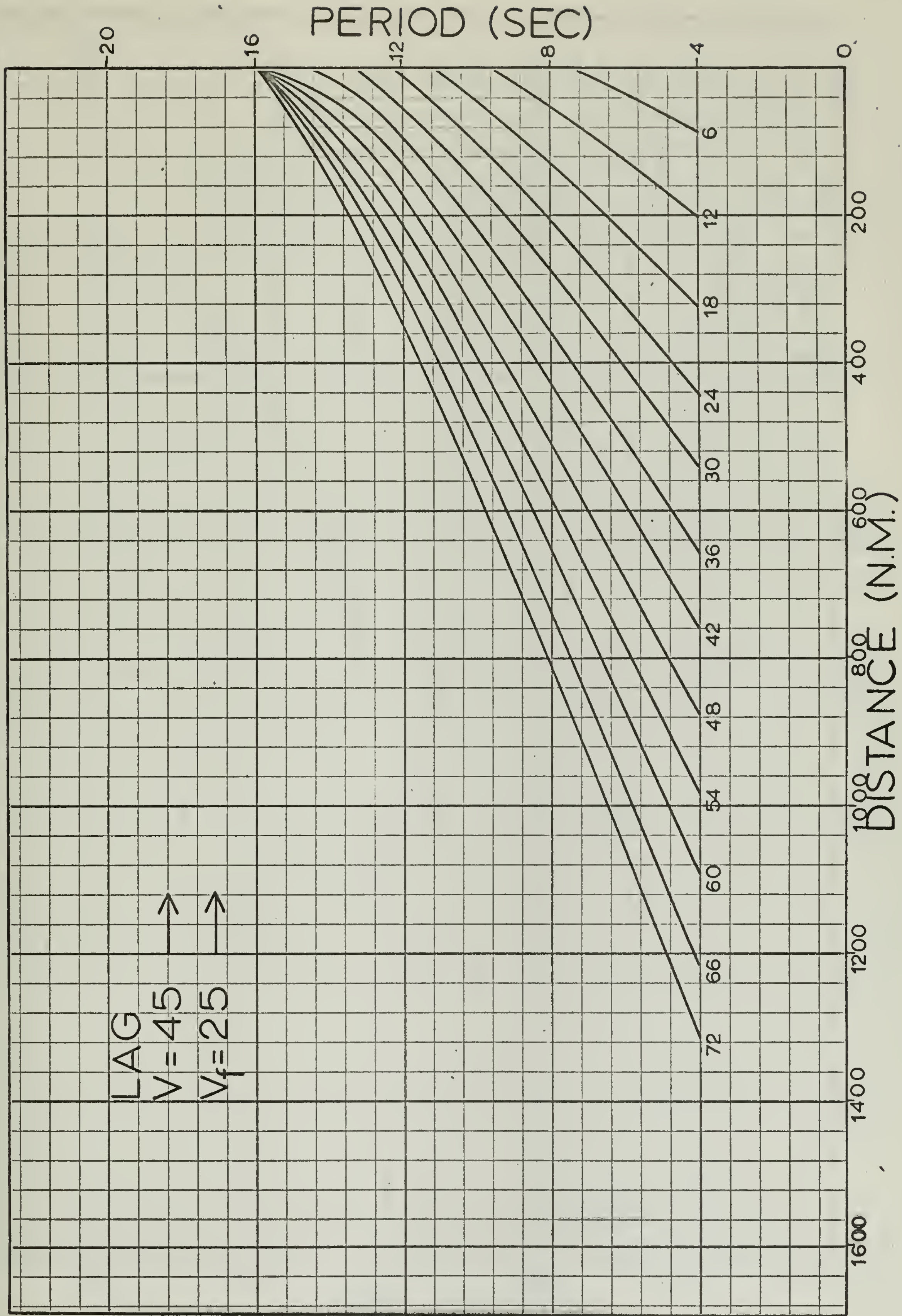

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
125
250
375
500
625
750
875
1000
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 45
Vf = 20

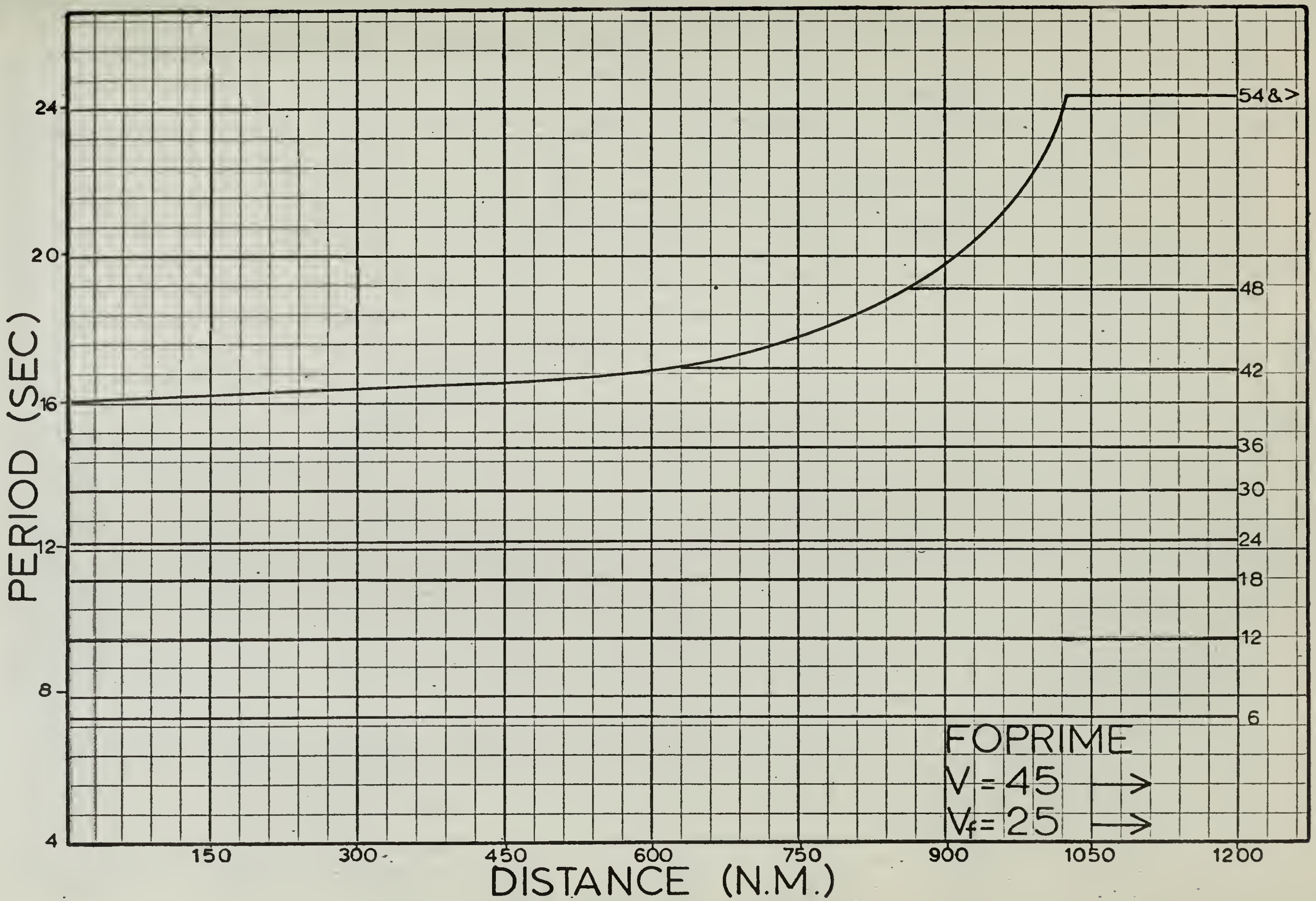

54 &>
48
42
36
30
24
18
12
6
FOPRIME
V = 45
$V_f$ = 20
24
20
16
12
8
4
PERIOD (SEC)
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)


PERIOD (SEC)
DISTANCE (N.M.)
SUMDEL
V = 45
$V_f$ = 20
54
60
72
54>
48
42
36
30
24
18
12
6

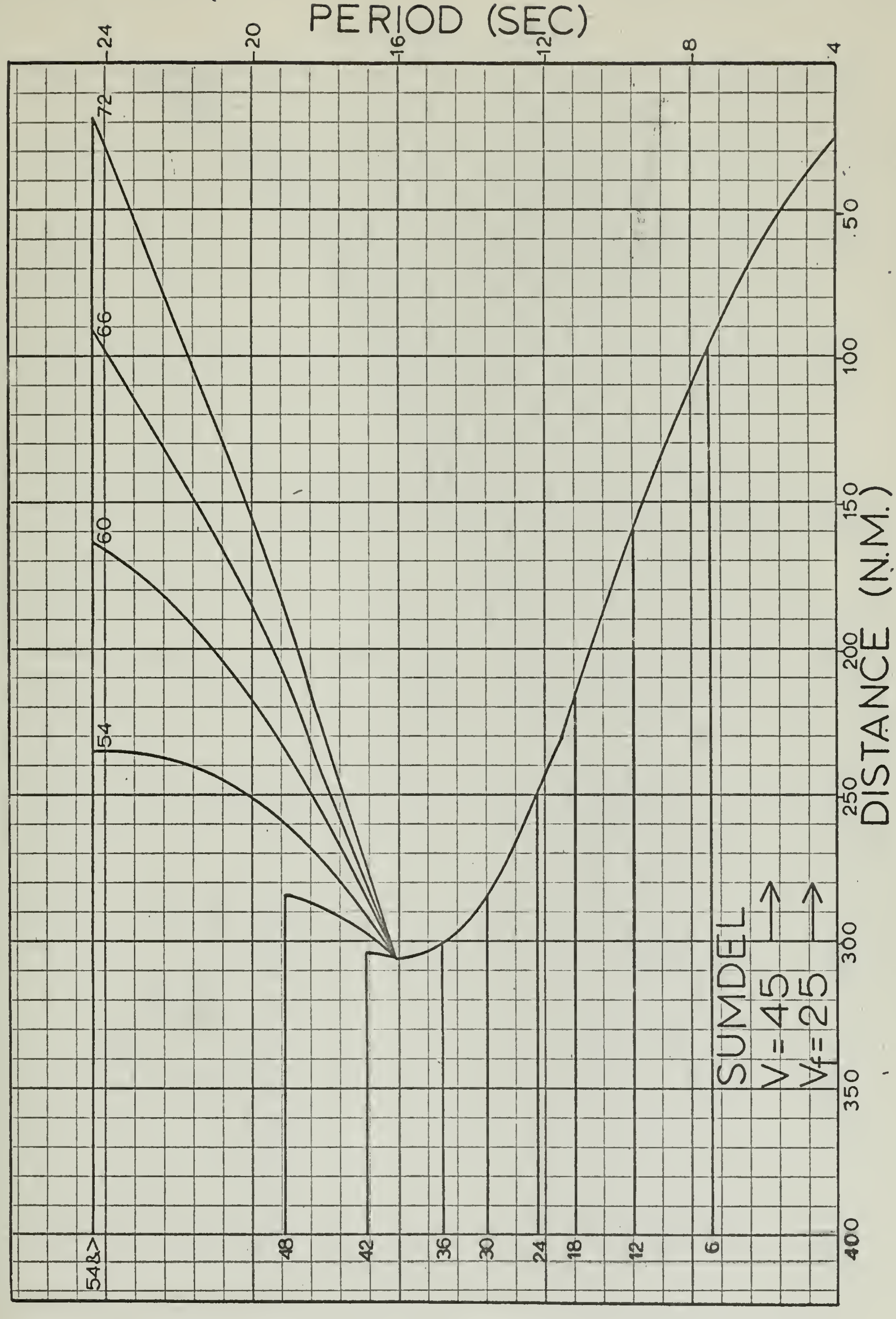


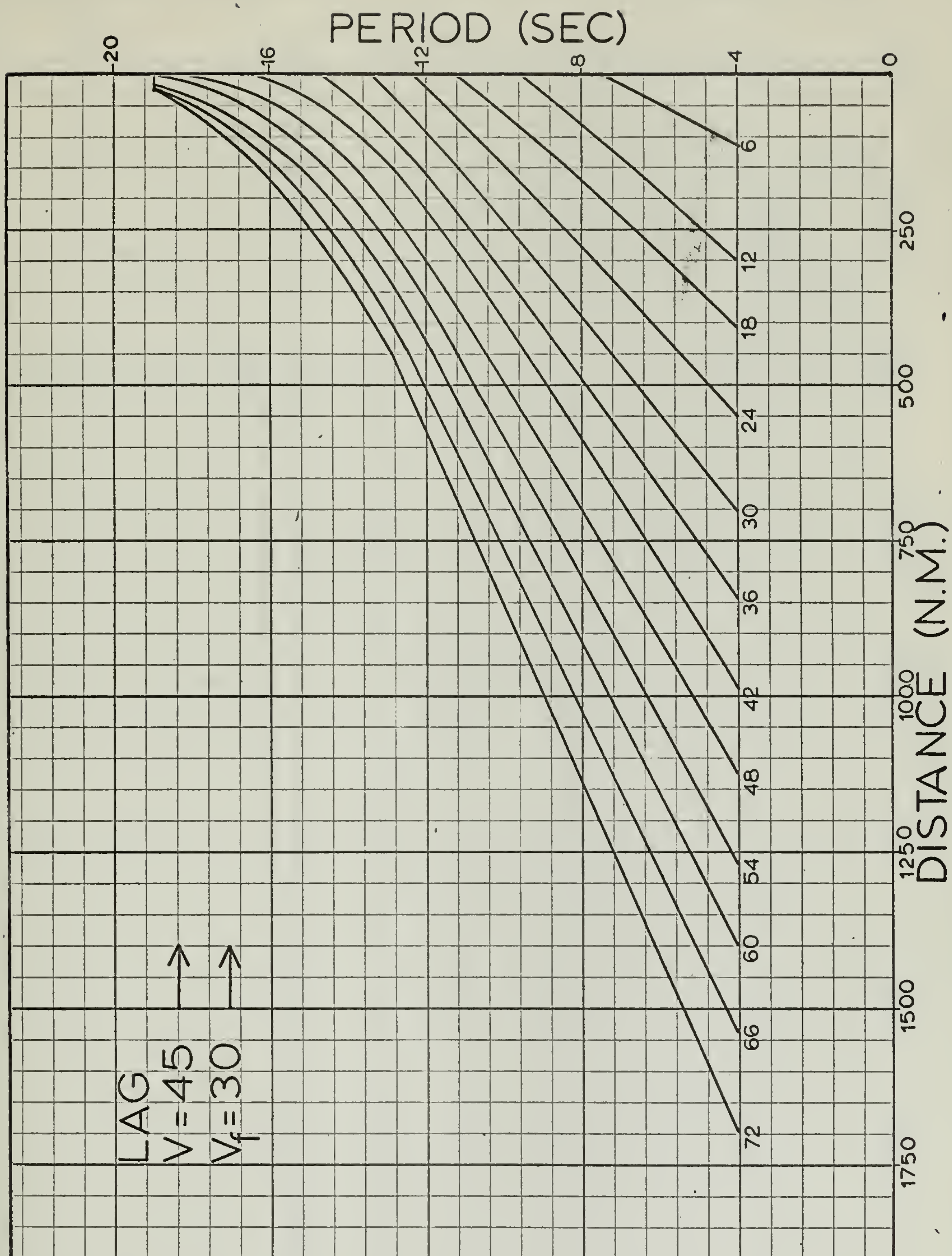
SWELL
V = 45
V_f = 20
DISTANCE (N.M.)
PERIOD (SEC)
54
60
66
72
50
100
150
200
250
300
350
400
24
20
16
12
8
4

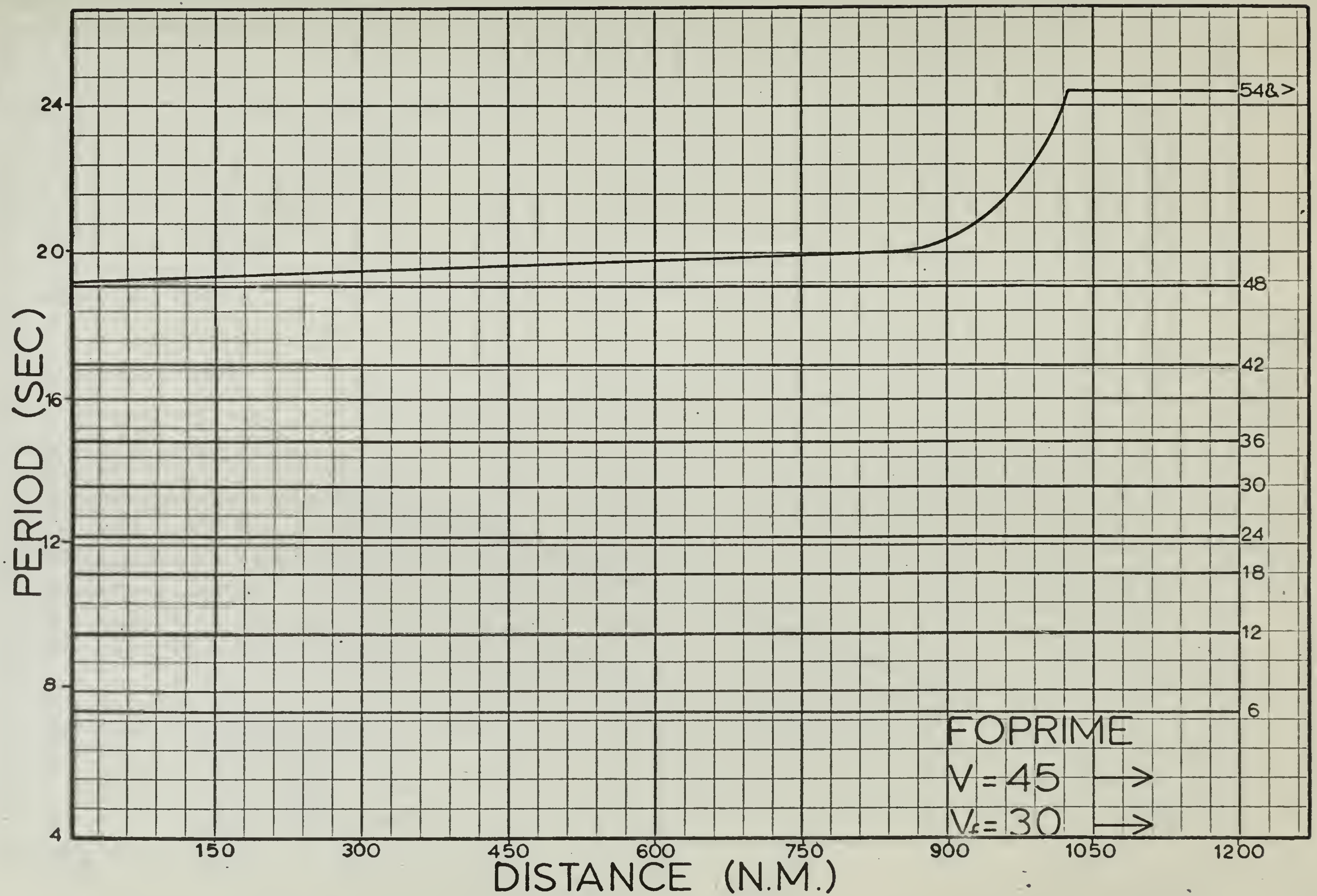

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 45
Vf = 25

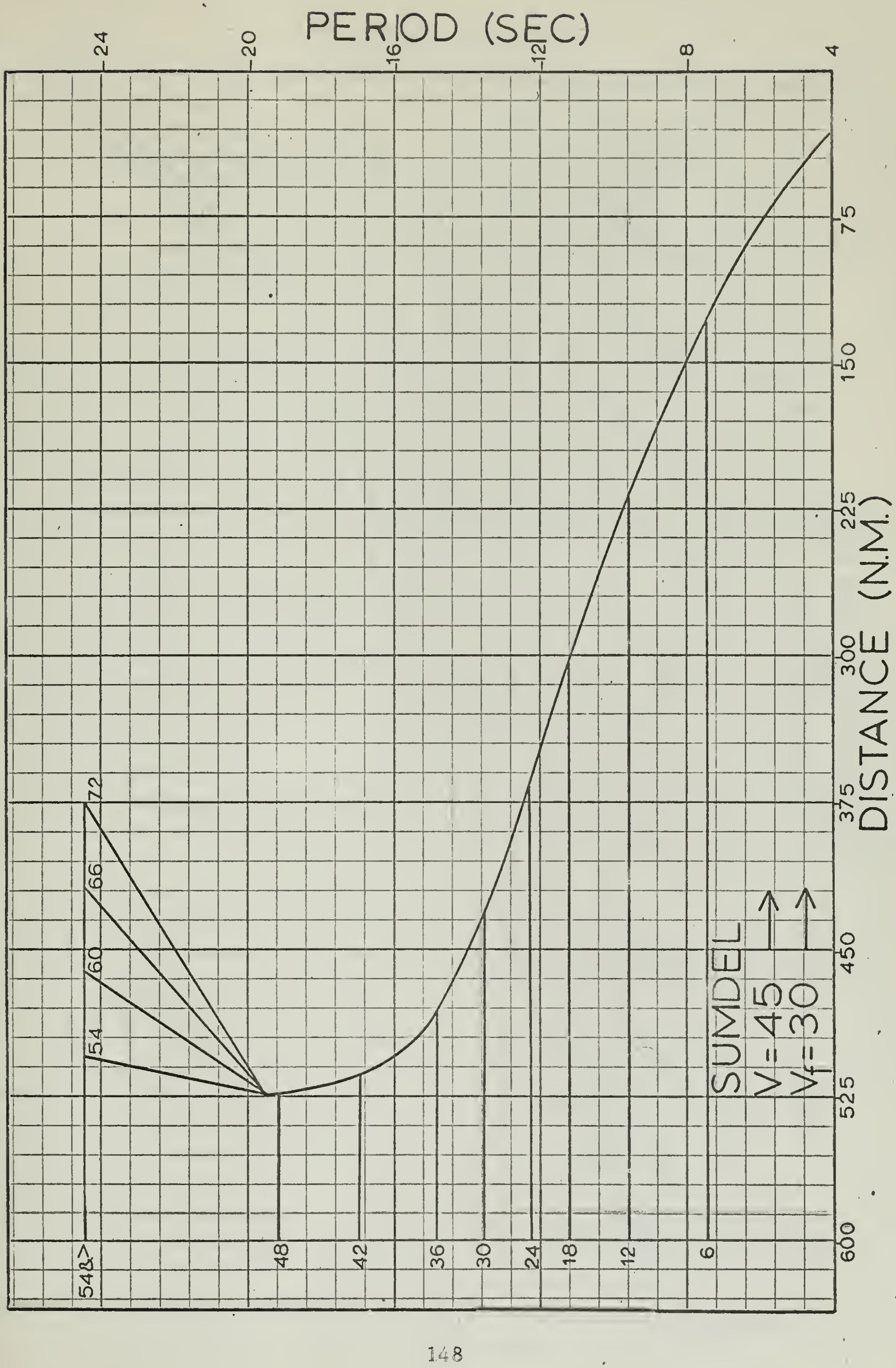


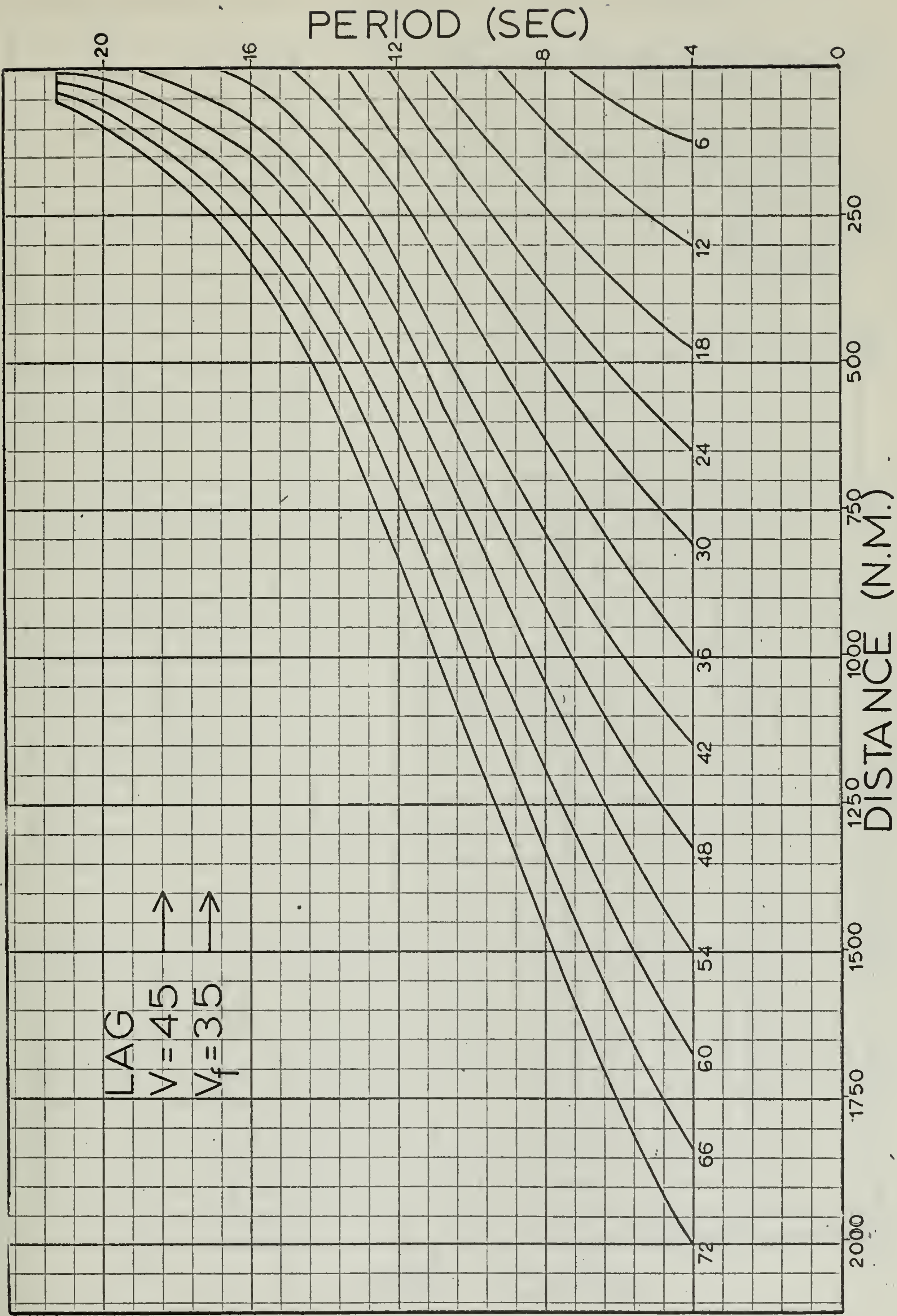
54&>
48
42
36
30
24
18
12
6
24
20
16
12
8
4
PERIOD (SEC)
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)
FOPRIME
V = 45 →
Vf = 25 →

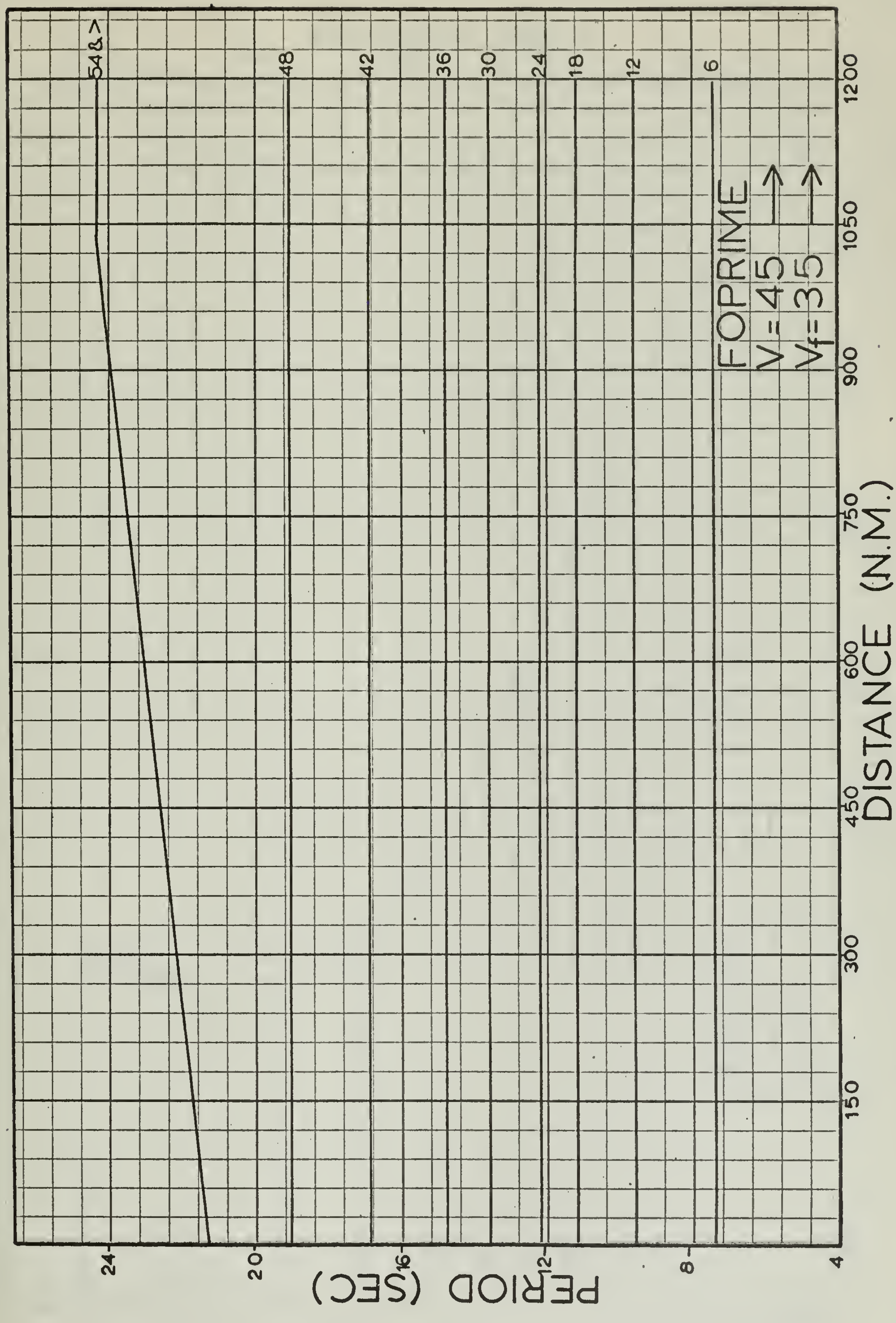

PERIOD (SEC)
DISTANCE (N.M.)
SUMDEL
V = 45
Vf = 25

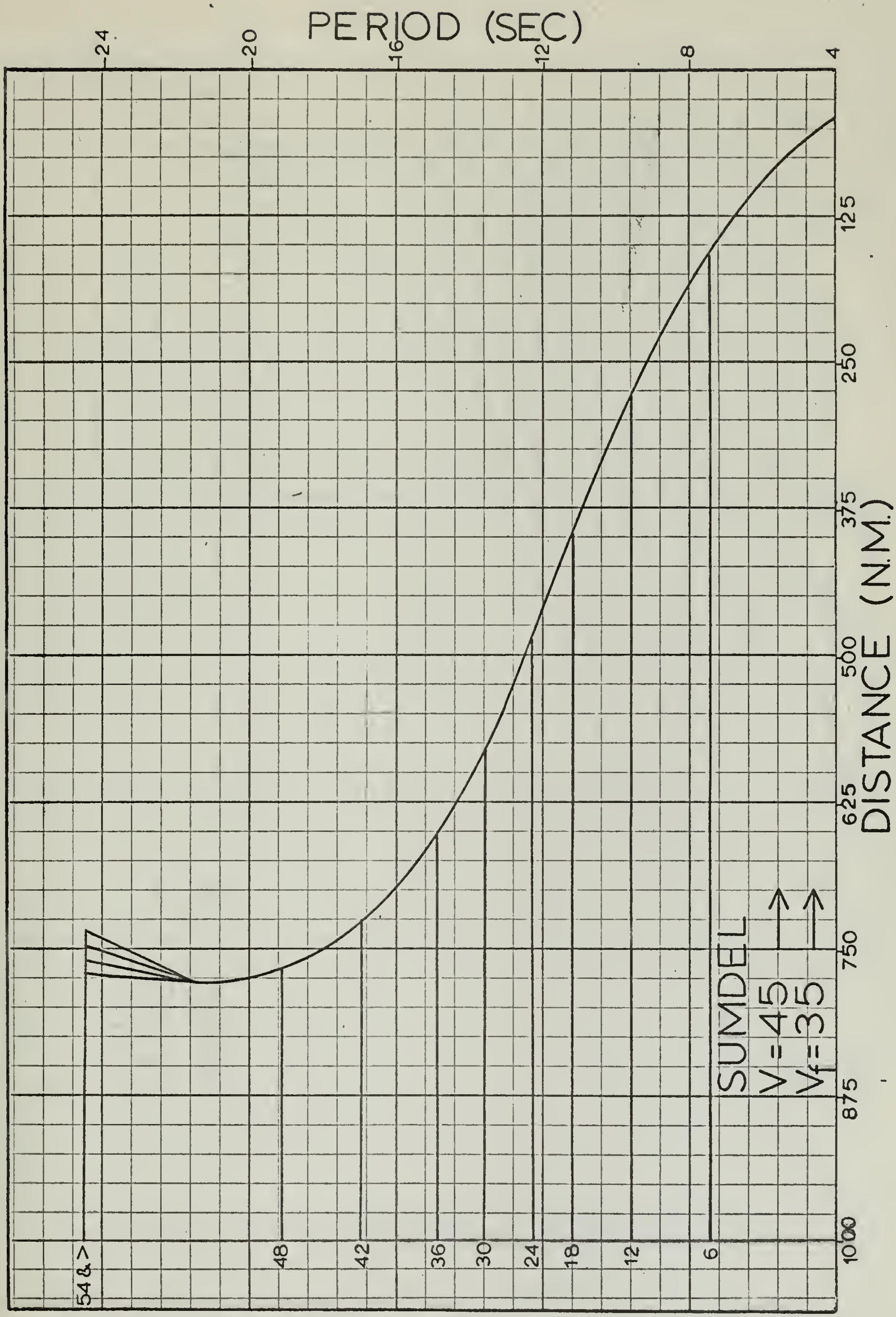

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
250
500
750
1000
1250
1500
1750
2000
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 45
V_f = 30

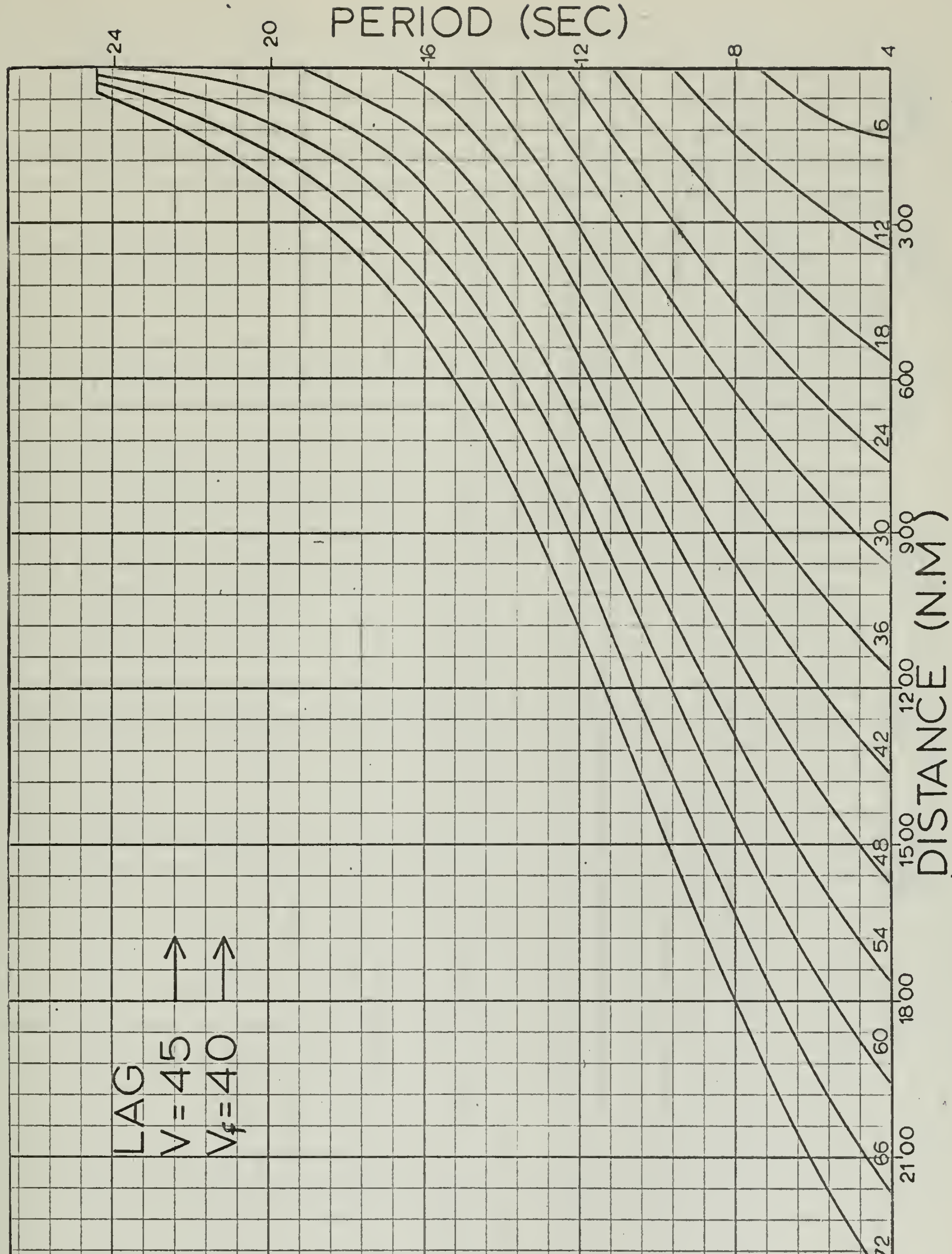

PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
150
300
450
600
750
900
1050
1200
54&>
48
42
36
30
24
18
12
6
FOPRIME
V = 45
V = 30

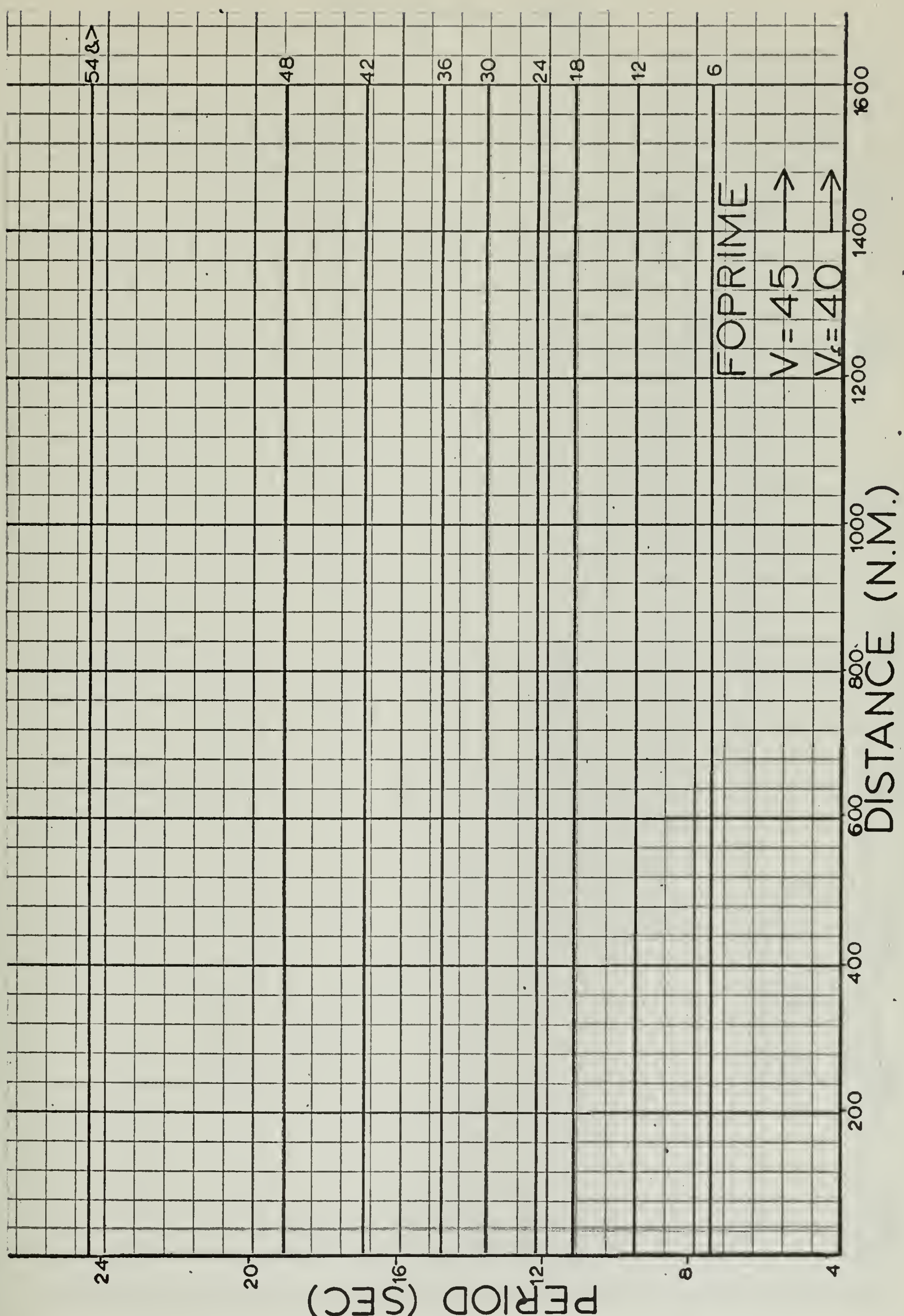

PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
75
150
225
300
375
450
525
600
72
66
60
54
54&>
48
42
36
30
24
18
12
6
SUMDEL
V = 45
Vf = 30

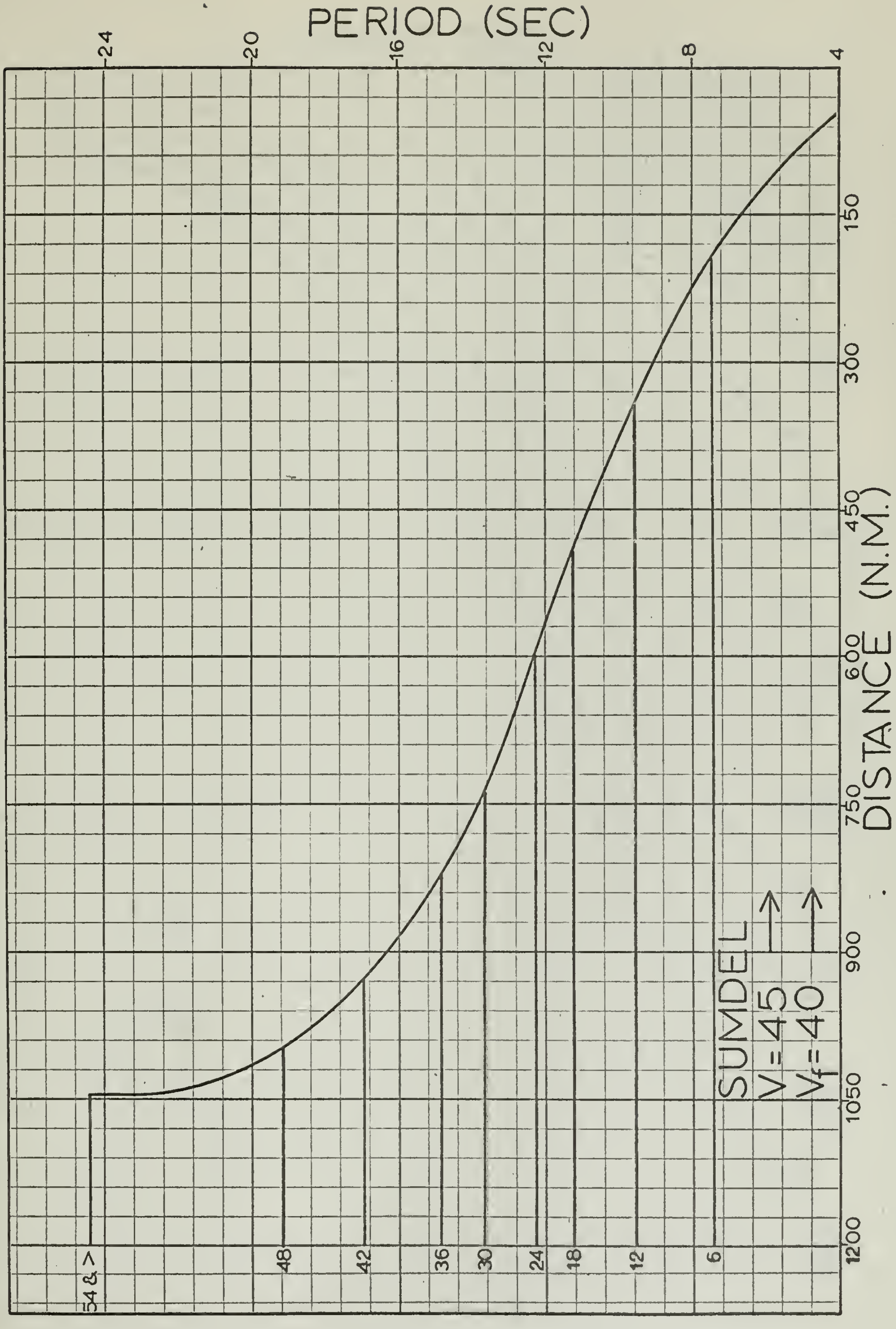

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
250
500
750
1000
1250
1500
1750
2000
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 45
V_f = 35

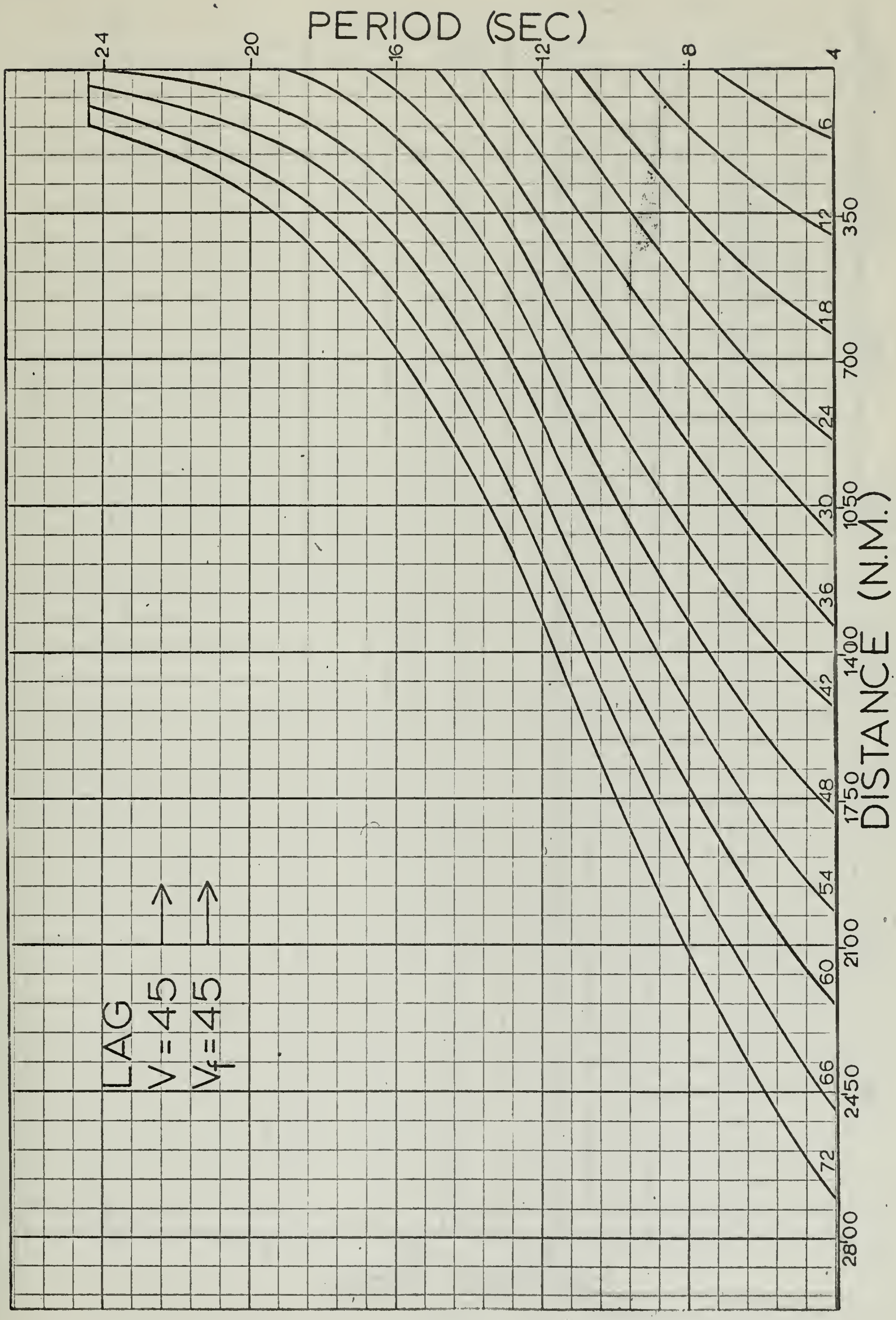

FOPRIME
V = 45
$V_f$ = 35
DISTANCE (N.M.)
150 300 450 600 750 900 1050 1200
PERIOD (SEC)
4 8 12 16 20 24
54&>
48
42
36
30
24
18
12
6

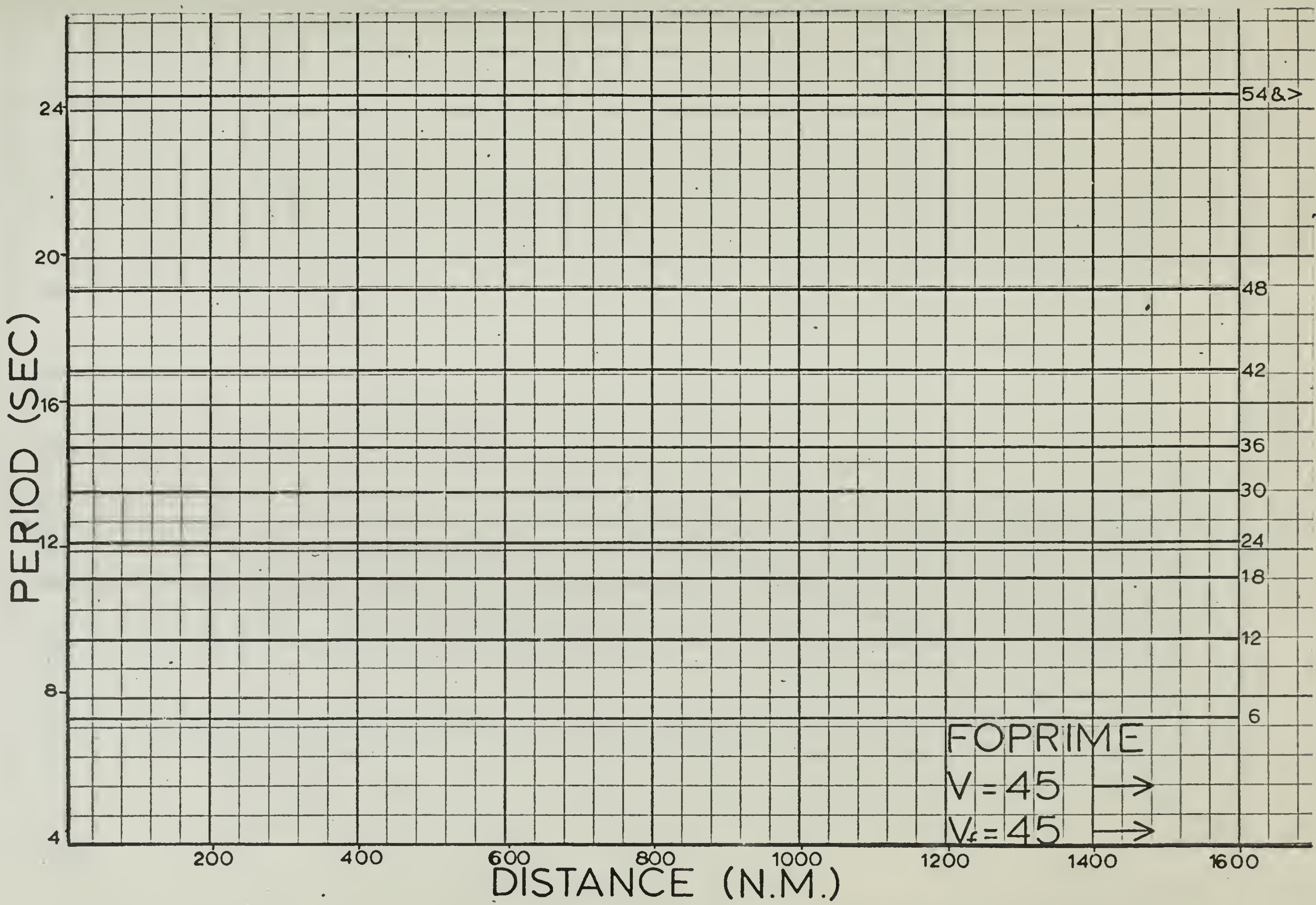

PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
125
250
375
500
625
750
875
1000
54 & >
48
42
36
30
24
18
12
6
SUMDEL
V = 45
Vf = 35


PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M)
300
600
900
1200
1500
1800
2100
2400
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 45
Vc = 40

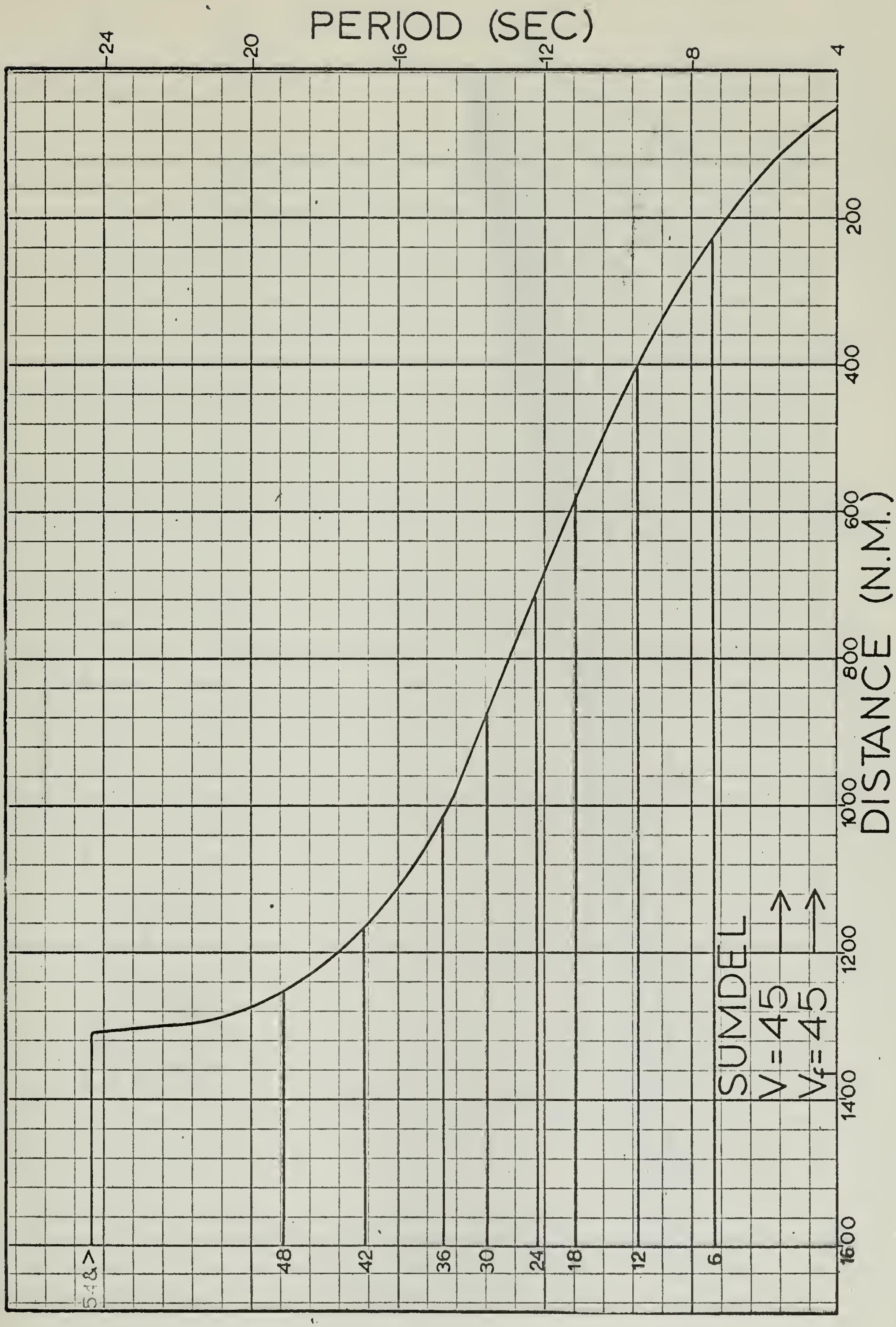

FOPRIME
V = 45
V = 40
DISTANCE (N.M.)
PERIOD (SEC)
54 & >
48
42
36
30
24
18
12
6
0
200
400
600
800
1000
1200
1400
1600
4
8
12
16
20
24

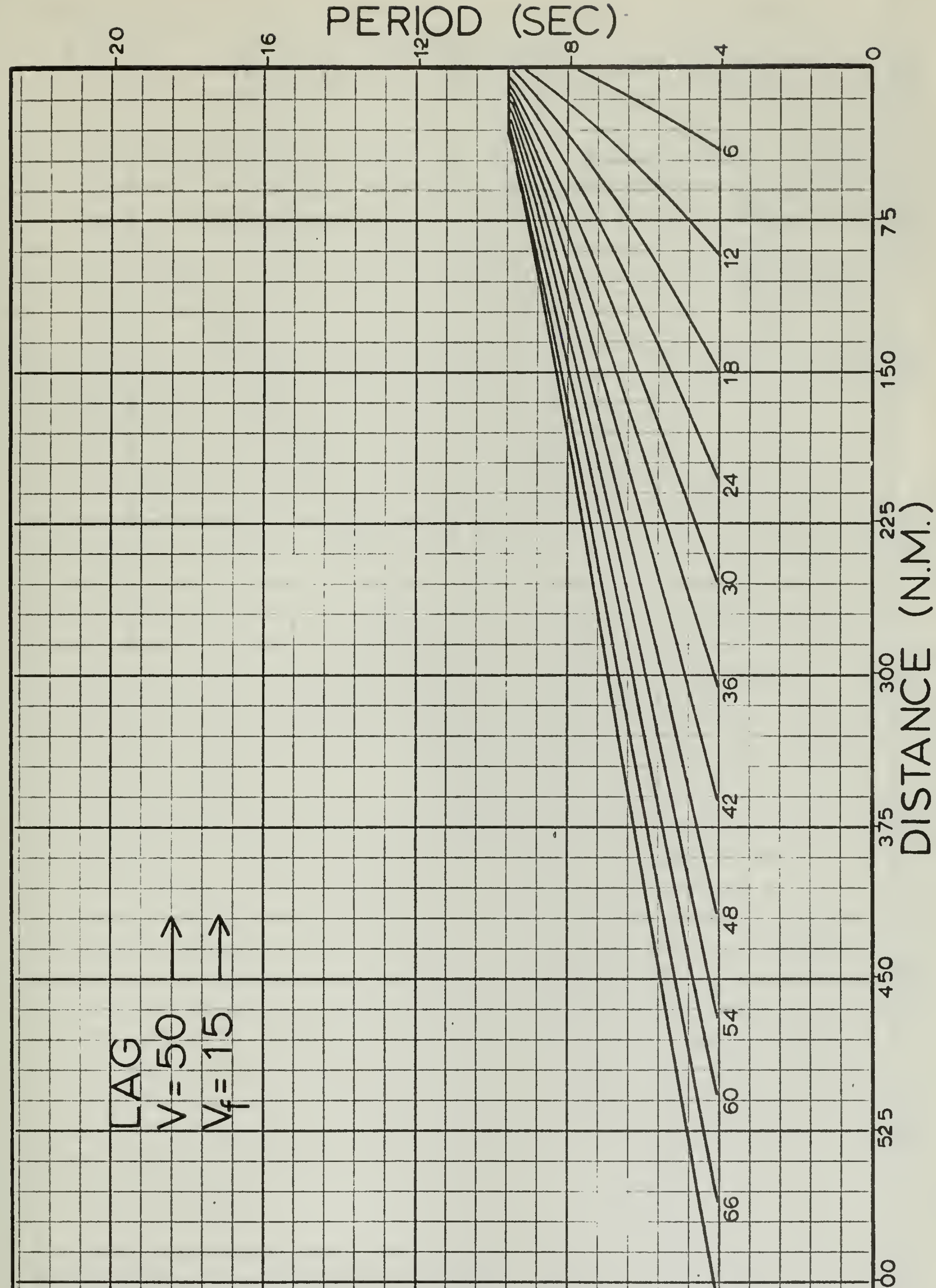

PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
150
300
450
600
750
900
1050
1200
SUMDEL
V = 45
$V_f$ = 40
54 & >
48
42
36
30
24
18
12
6

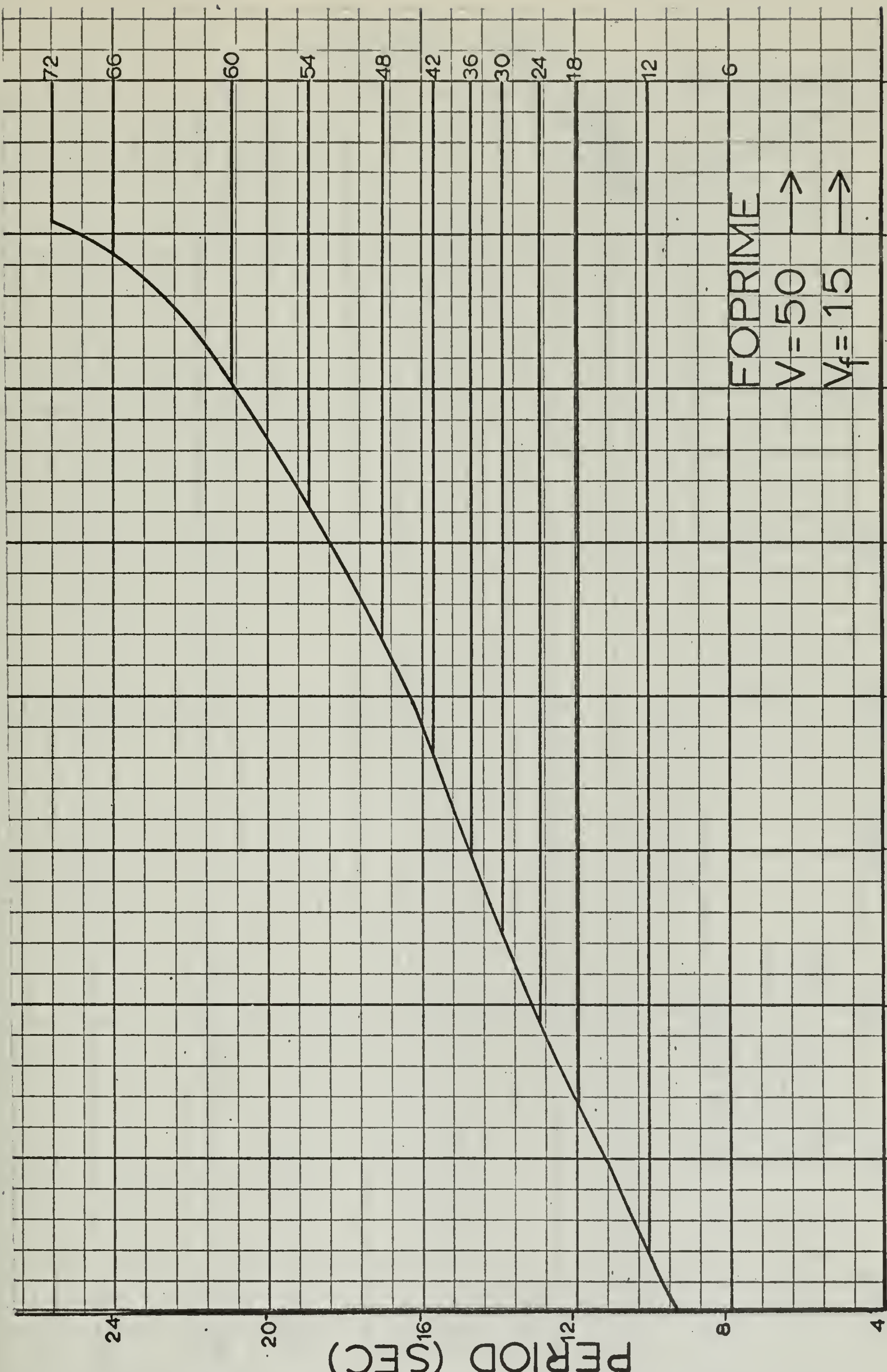

PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
350
700
1050
1400
1750
2100
2450
2800
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 45
Vf = 45



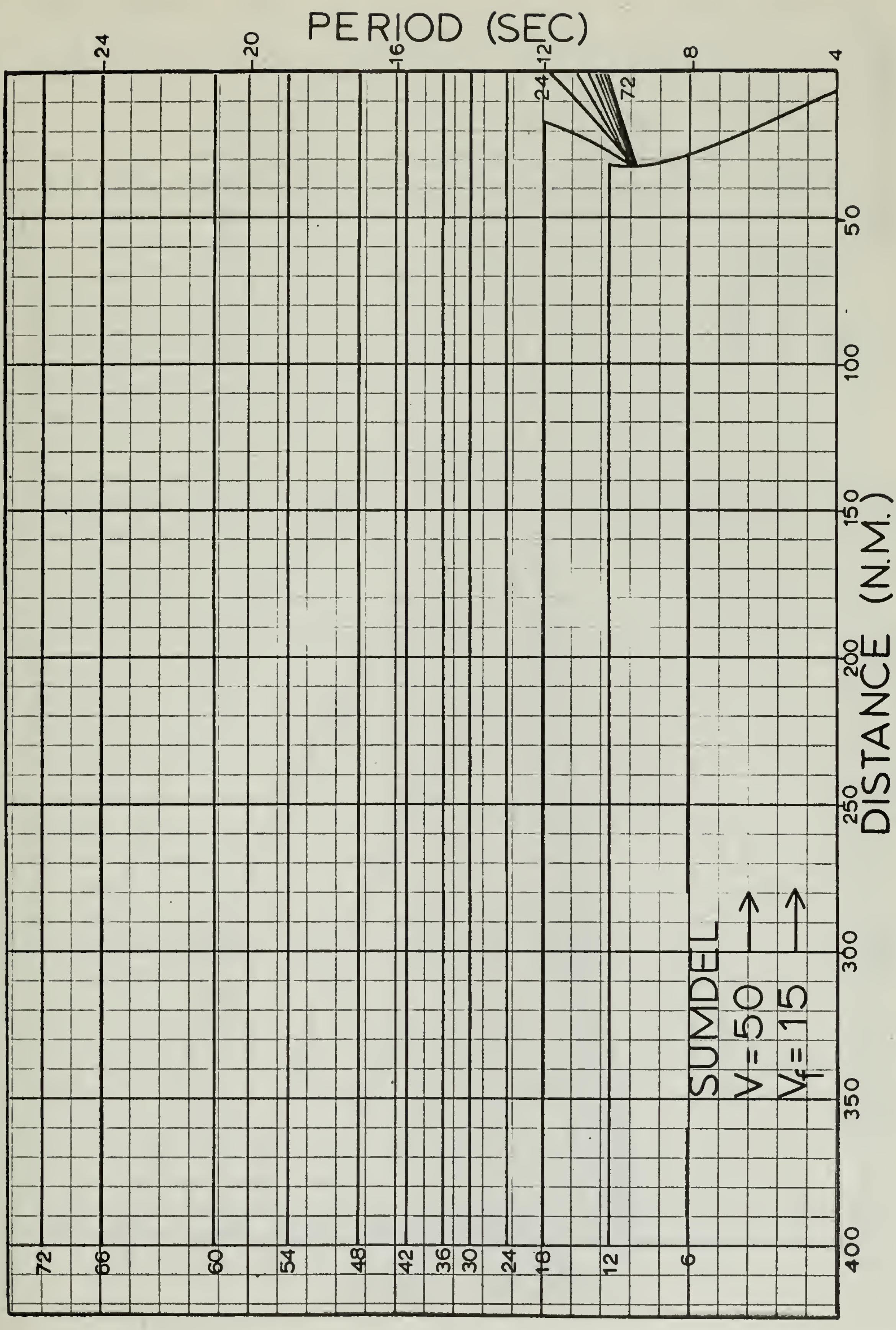
FOPRIME
V = 45 →
$V_f$ = 45 →
54&>
48
42
36
30
24
18
12
6
PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600

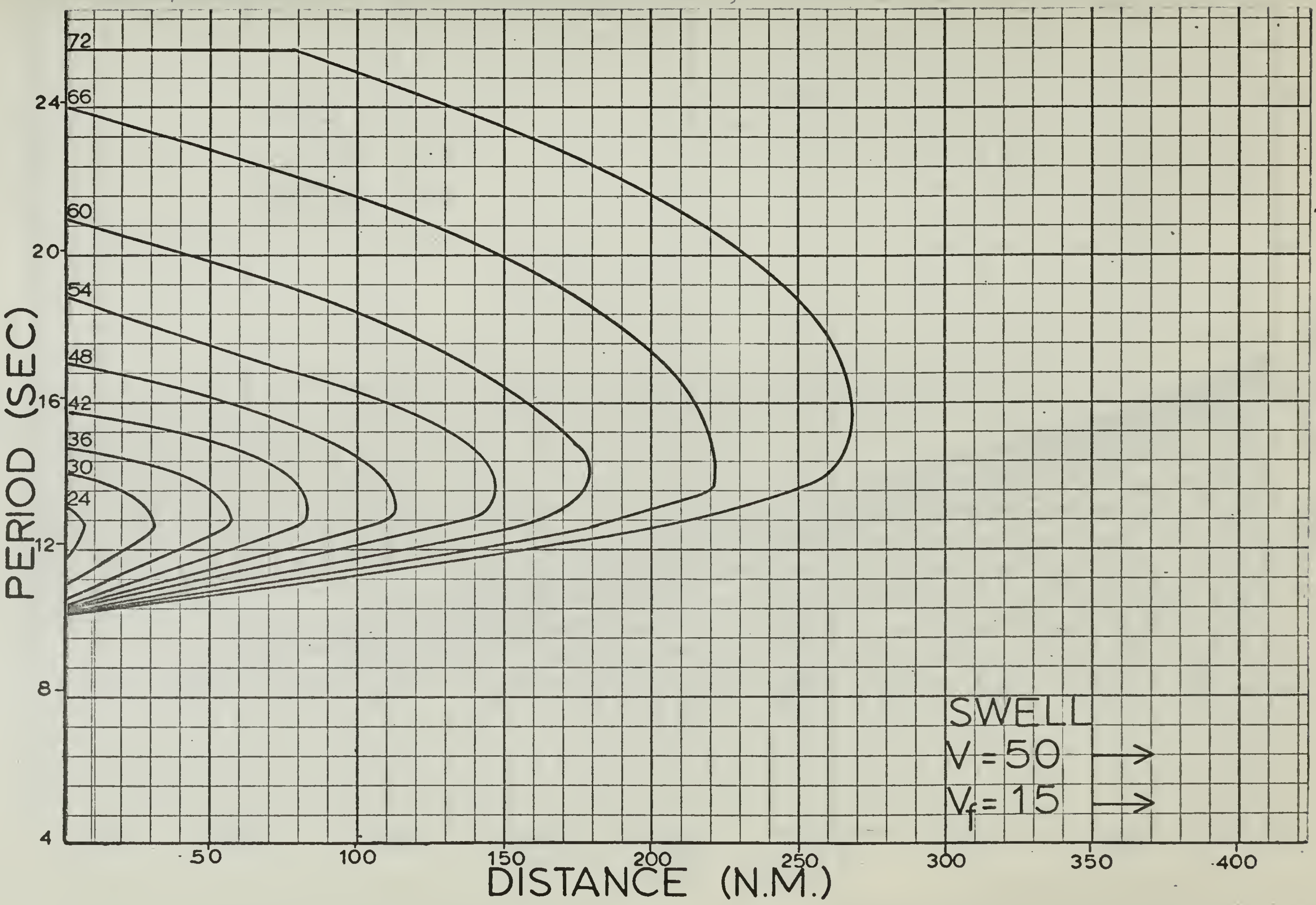

PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
54 &>
48
42
36
30
24
18
12
6
SUMDEL
V = 45
$V_f$ = 45


PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
75
150
225
300
375
450
525
600
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 50
$V_f$ = 15

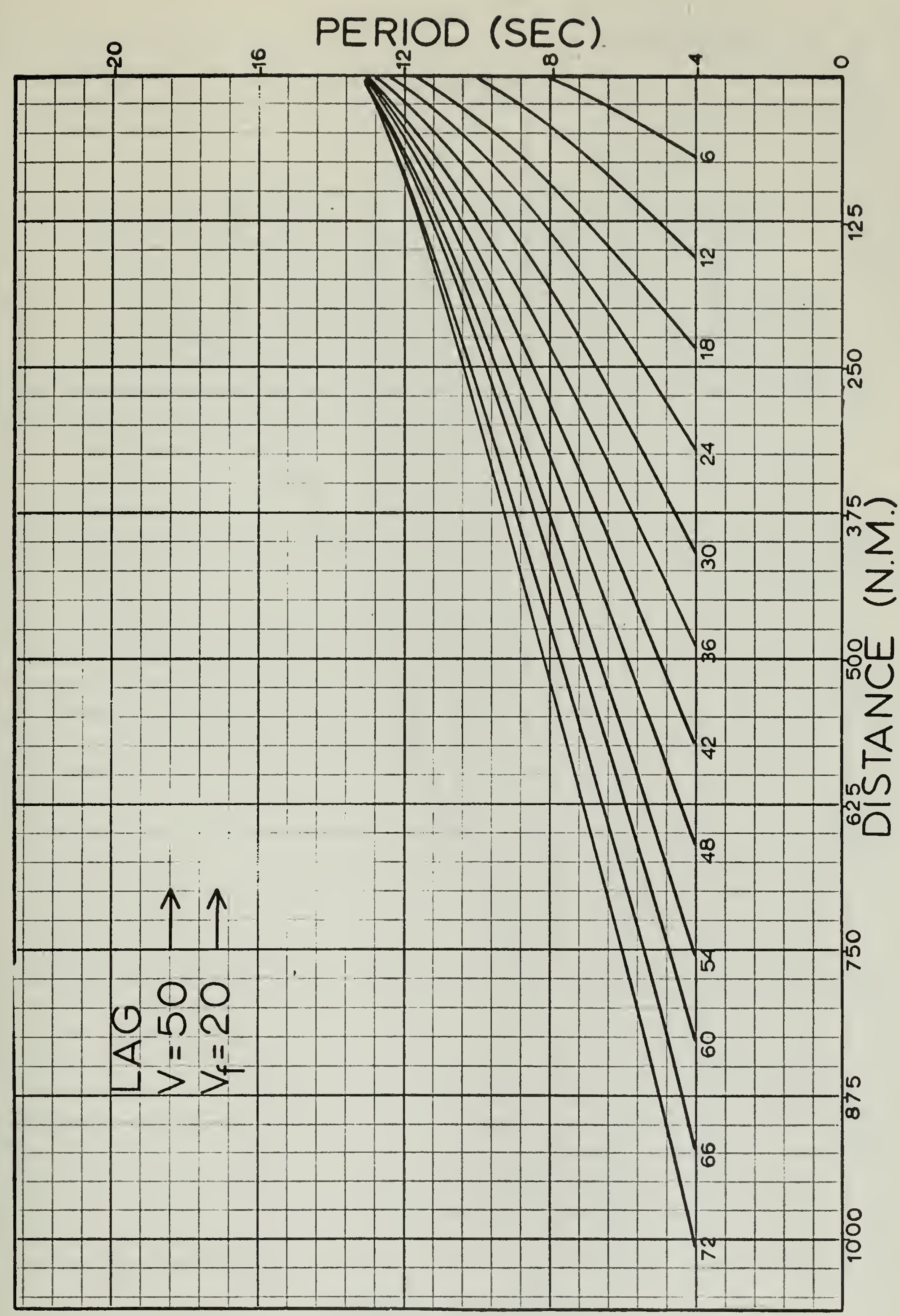


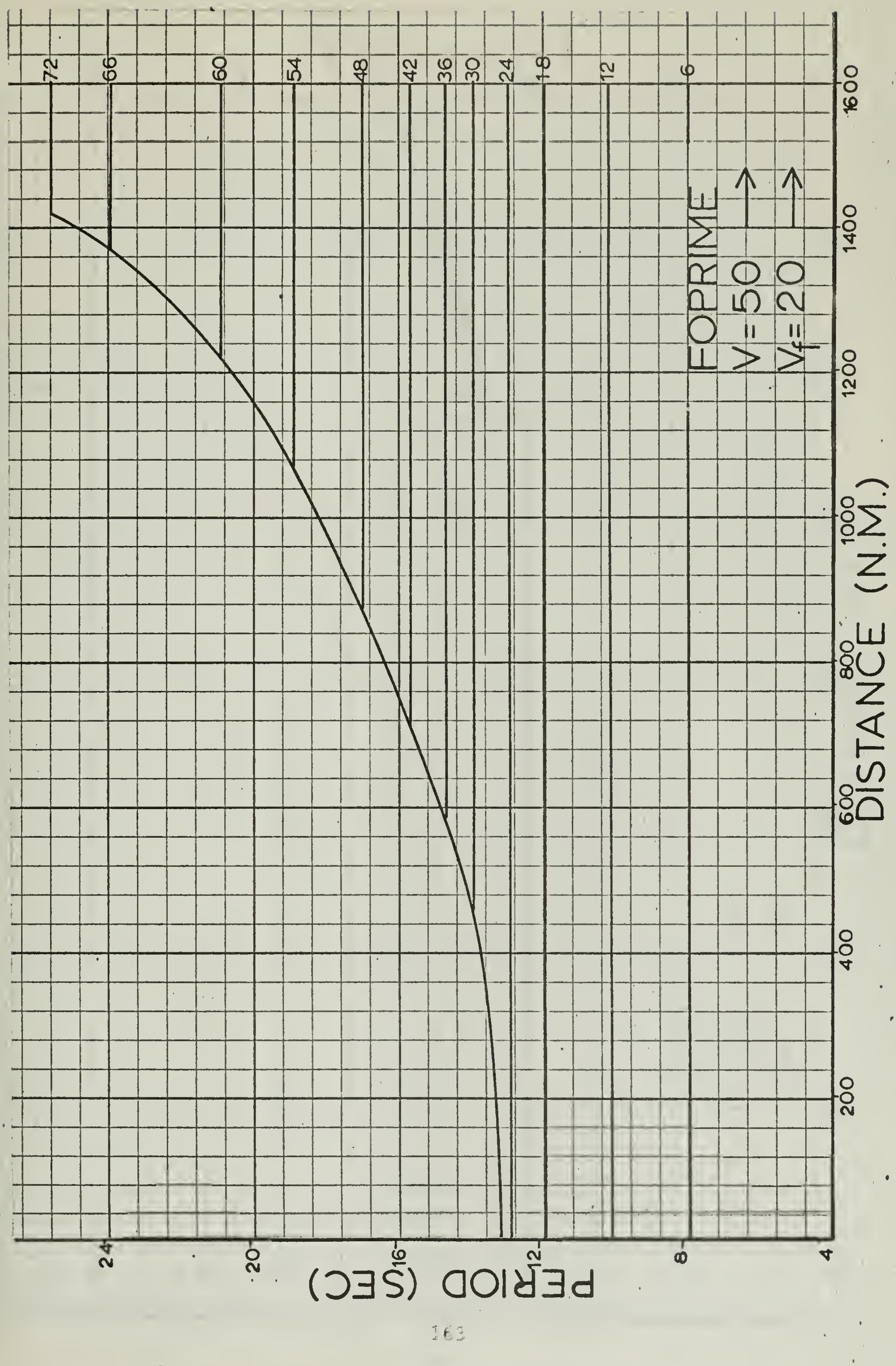
FOPRIME
V = 50
$V_f$ = 15
DISTANCE (N.M.)
PERIOD (SEC)
200
400
600
800
1000
1200
1400
1600
4
8
12
16
20
24
6
12
18
24
30
36
42
48
54
60
66
72

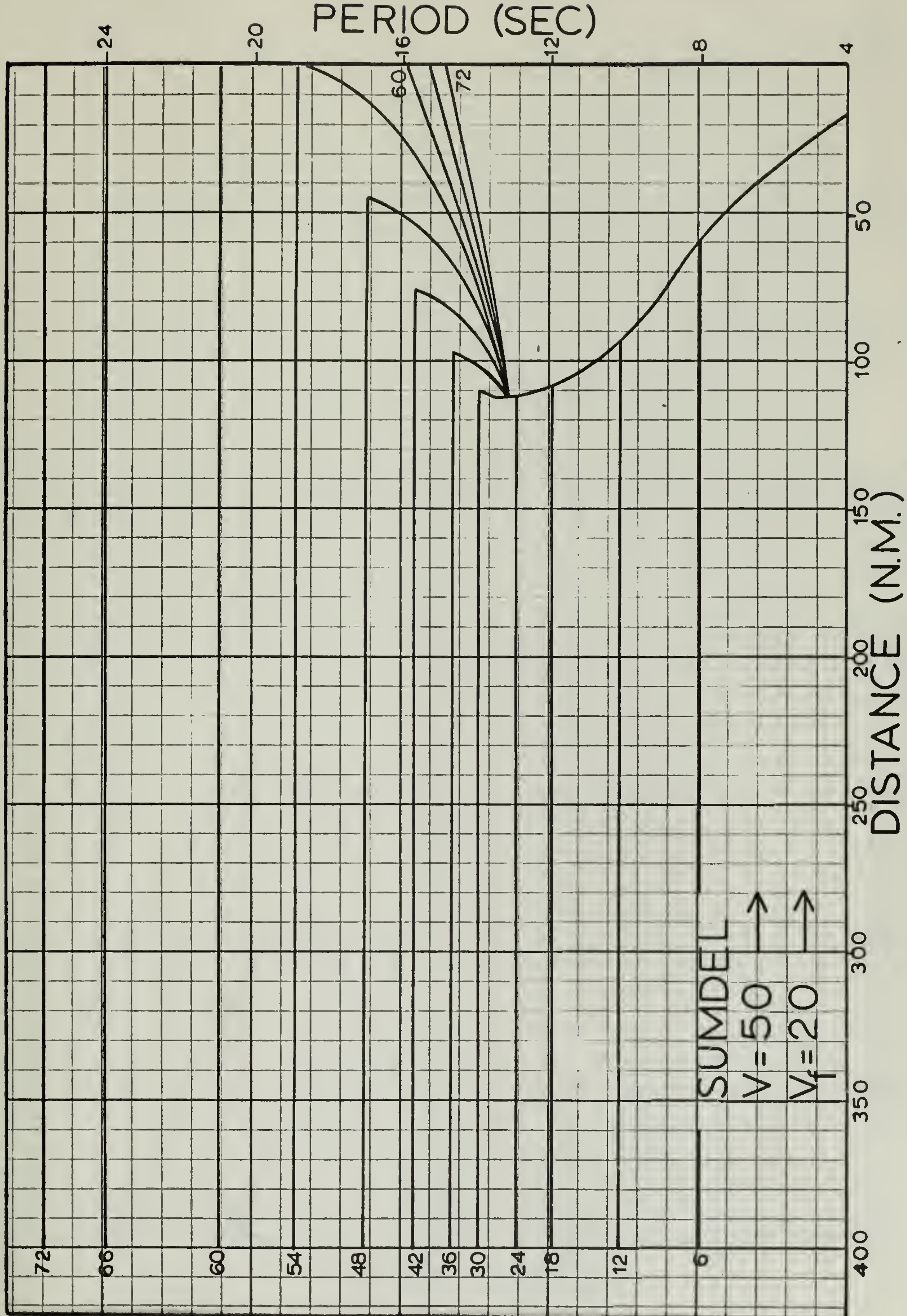

PERIOD (SEC)
DISTANCE (N.M.)
SUMDEL
V = 50
Vf = 15



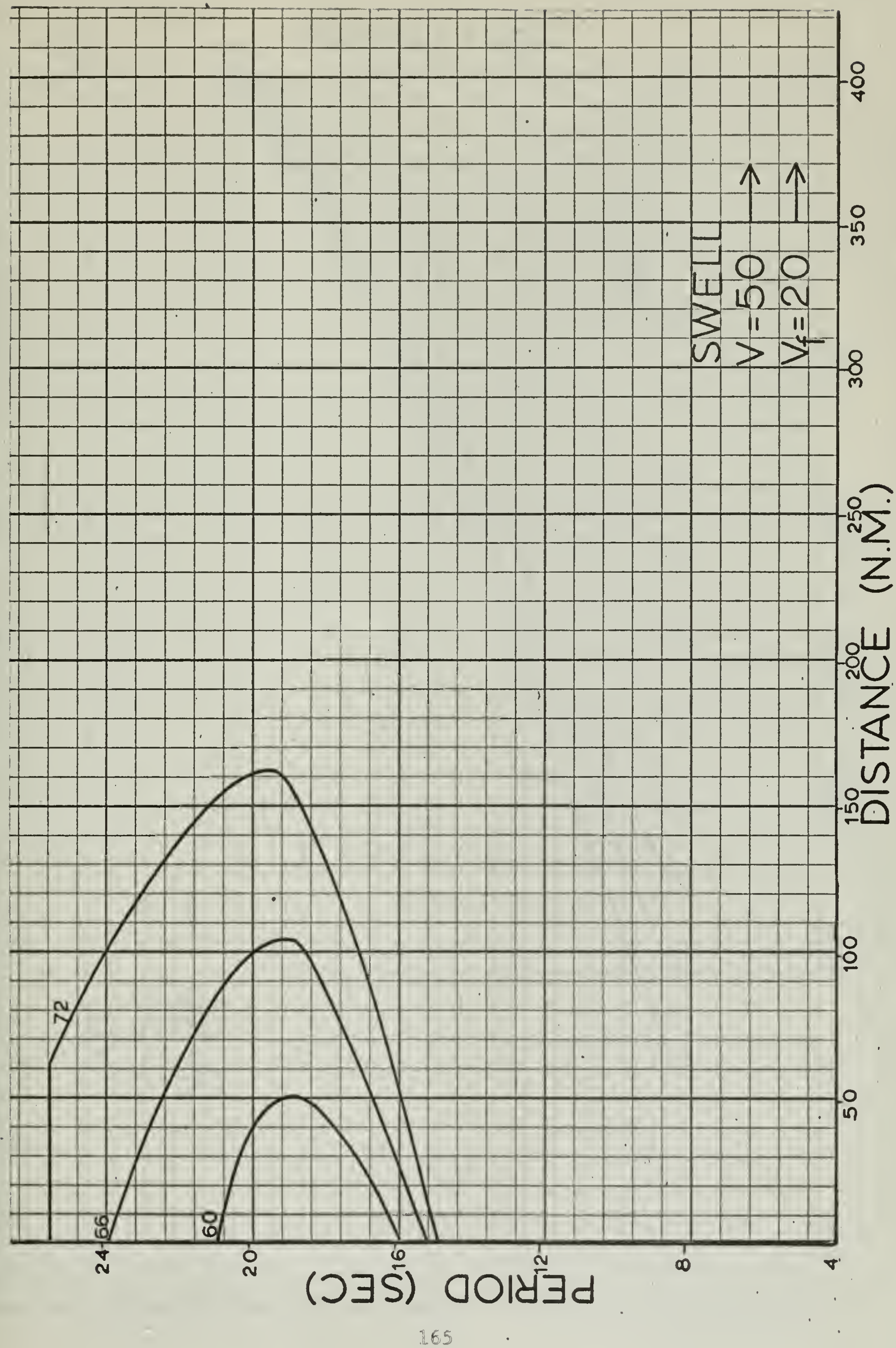
72
66
60
54
48
42
36
30
24
24
20
16
12
8
4
PERIOD (SEC)
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
SWELL
V = 50
V_f = 15

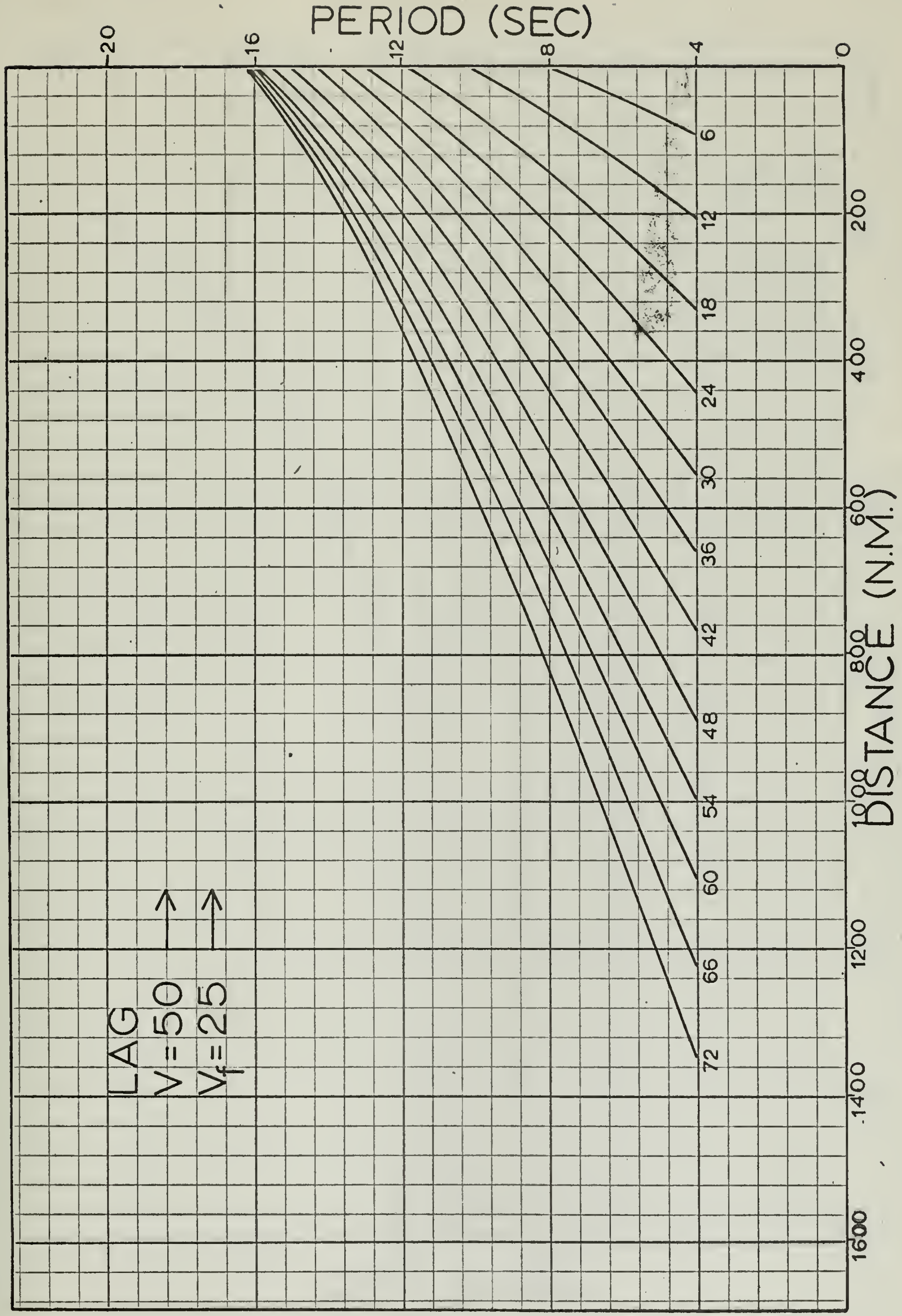

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
125
250
375
500
625
750
875
1000
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 50
$V_f$ = 20

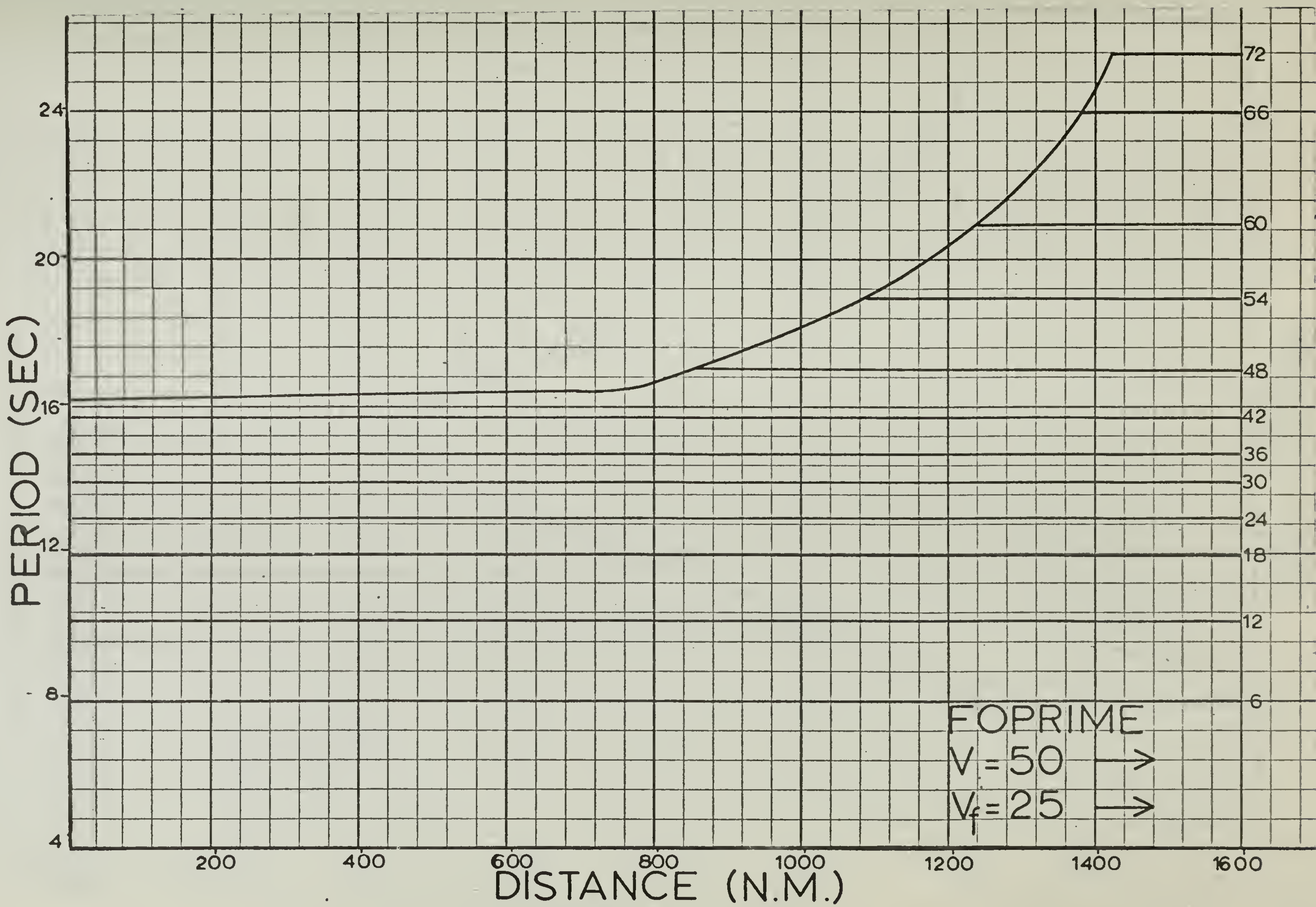

FOPRIME
V = 50
$V_f$ = 20
DISTANCE (N.M.)
PERIOD (SEC)
72
66
60
54
48
42
36
30
24
18
12
6
200
400
600
800
1000
1200
1400
1600
4
8
12
16
20
24

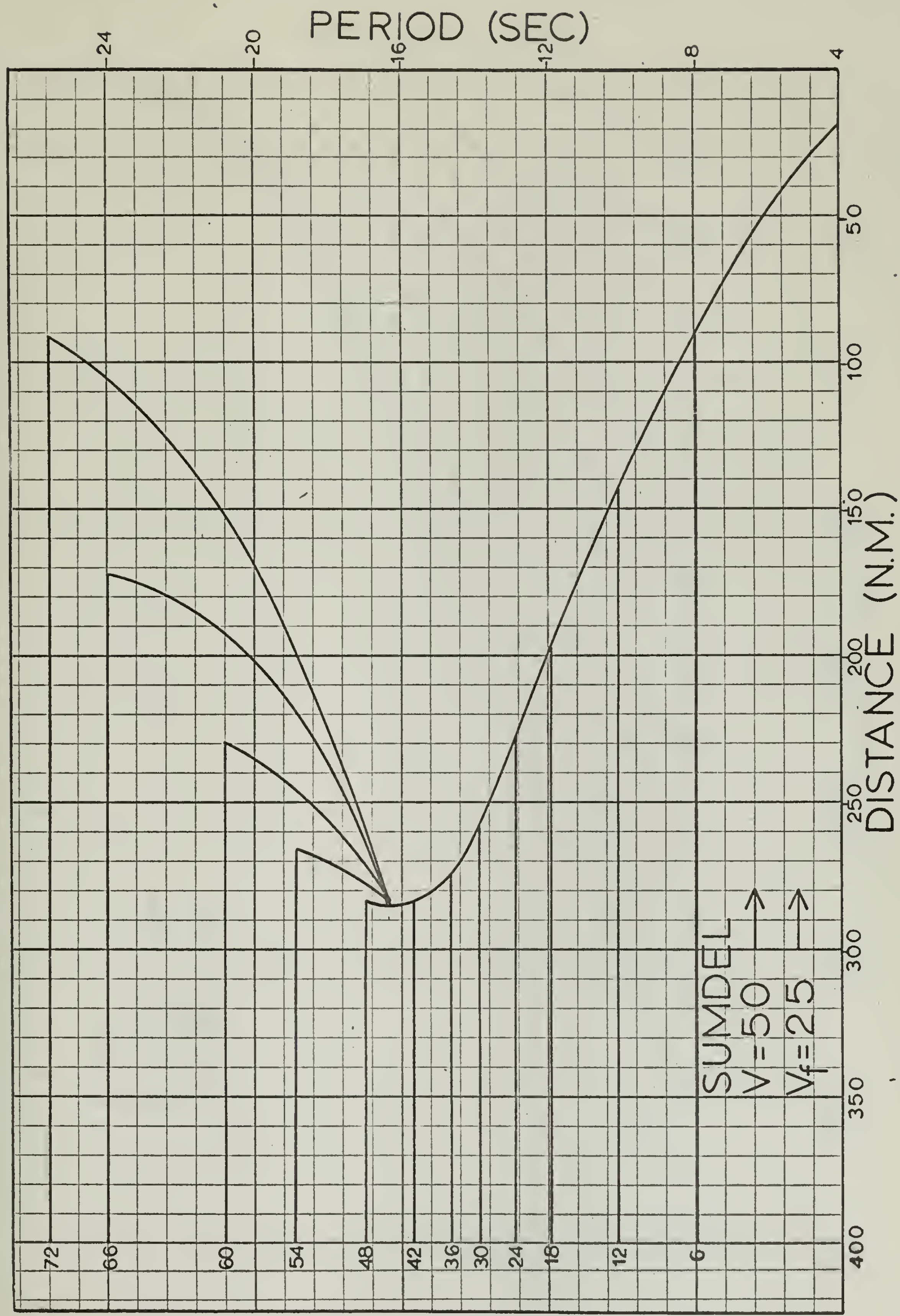


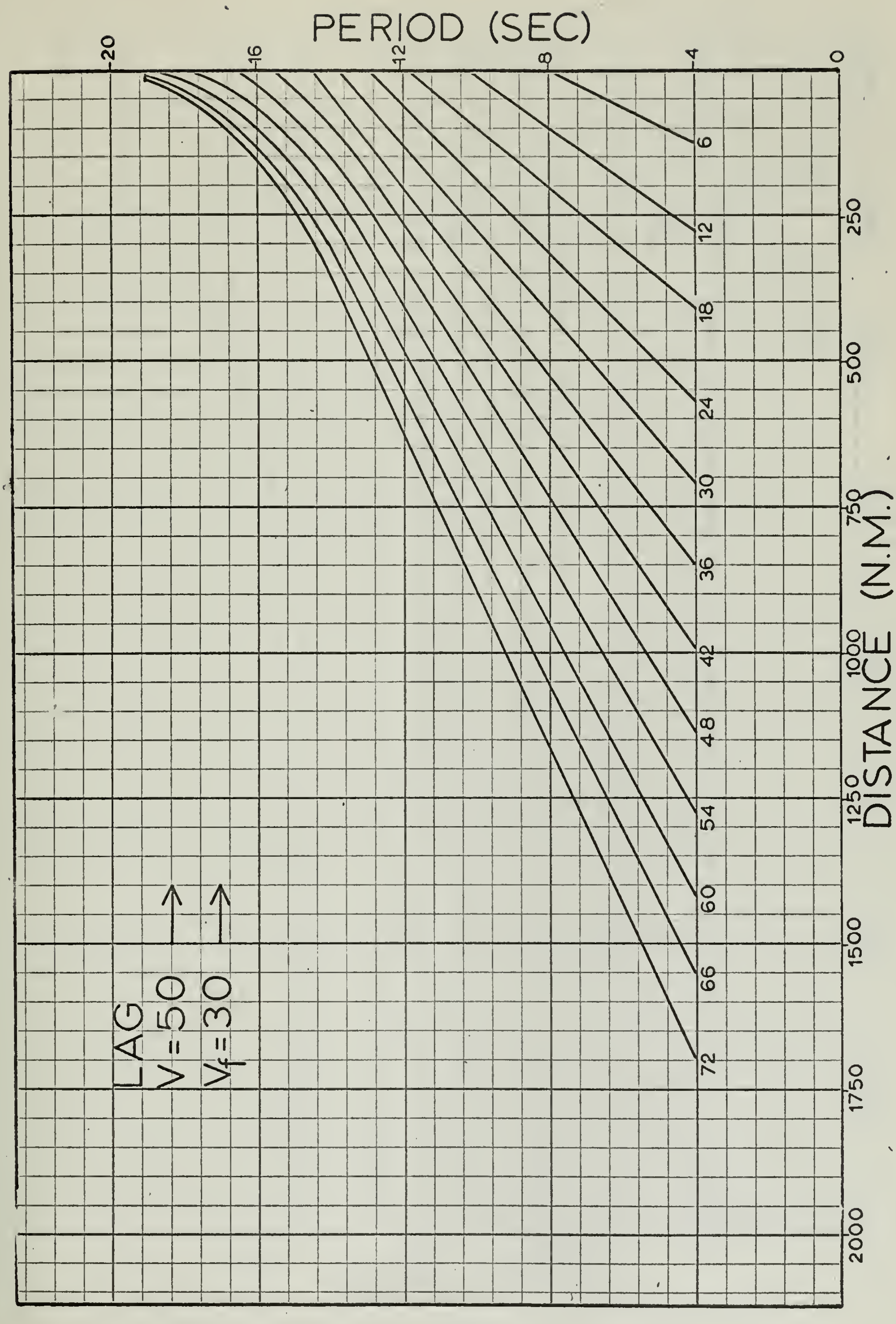
PERIOD (SEC)
DISTANCE (N.M.)
SUMDEL
V = 50
$V_f$ = 20
24
20
16
12
8
4
60
72
50
100
150
200
250
300
350
400
72
66
60
54
48
42
36
30
24
18
12
6

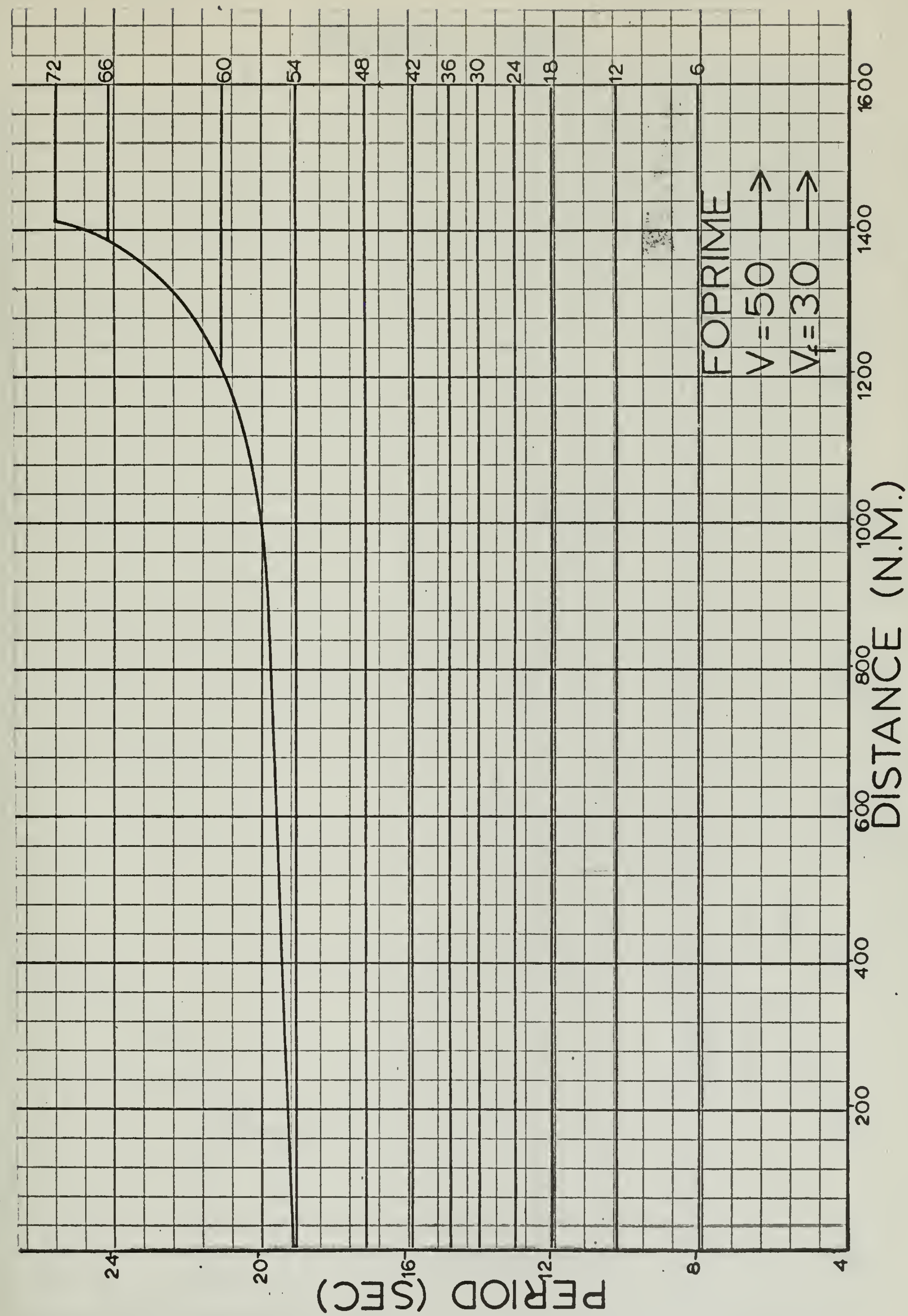

SWELL
V = 50
Vf = 20
72
66
60
24
20
16
12
8
4
PERIOD (SEC)
50
100
150
200
250
300
350
400
DISTANCE (N.M.)


PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 50
V_f = 25


PERIOD (SEC)
24
20
16
12
8
4
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
72
66
60
54
48
42
36
30
24
18
12
6
FOPRIME
V = 50
Vf = 25


PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
50
100
150
200
250
300
350
400
72
66
60
54
48
42
36
30
24
18
12
6
SUMDEL
V = 50 →
Vf = 25 →


PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
250
500
750
1000
1250
1500
1750
2000
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 50
$V_f$ = 30


FOPRIME
V = 50
Vf = 30
DISTANCE (N.M.)
PERIOD (SEC)
200
400
600
800
1000
1200
1400
1600
4
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16
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66
60
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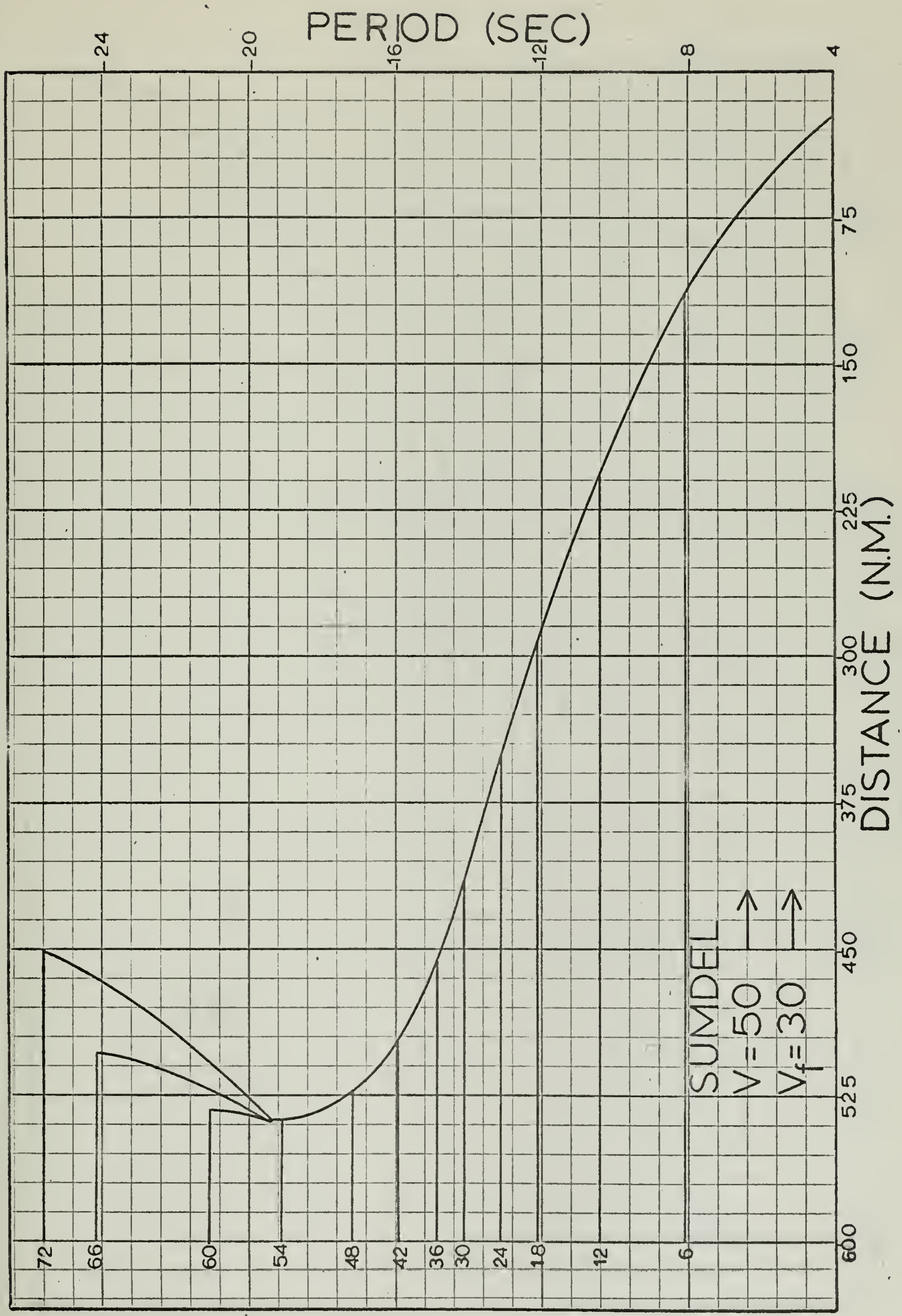
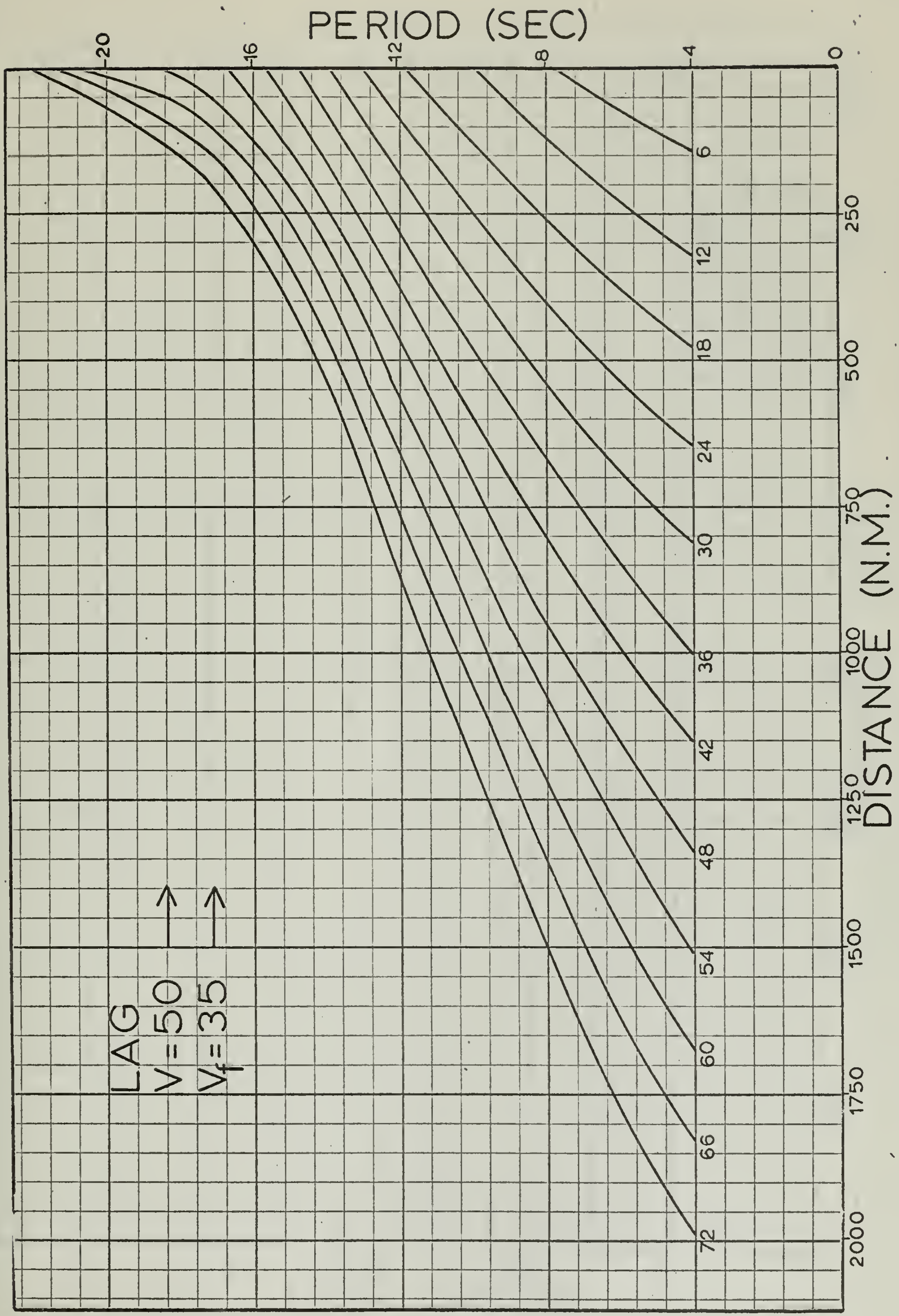
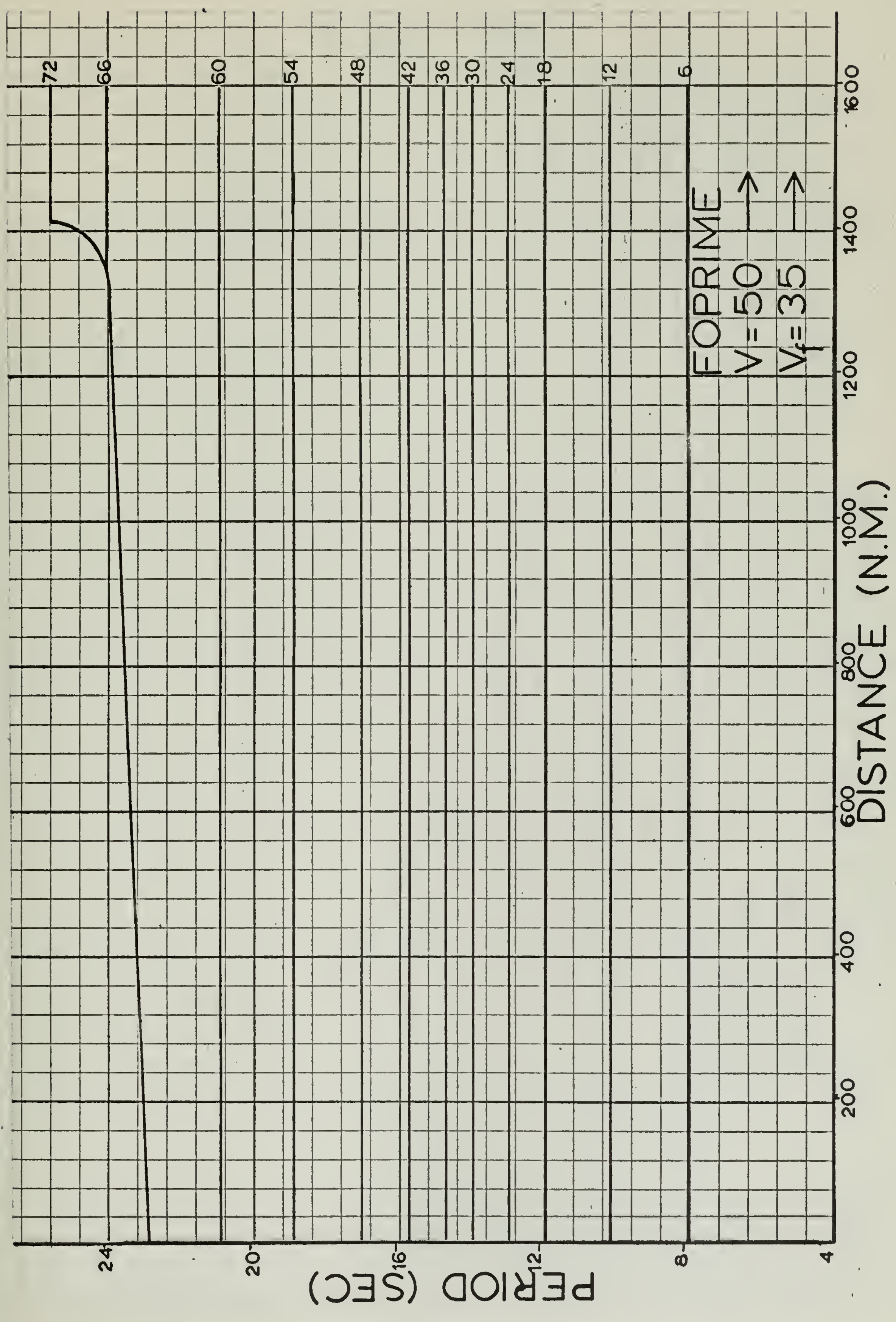
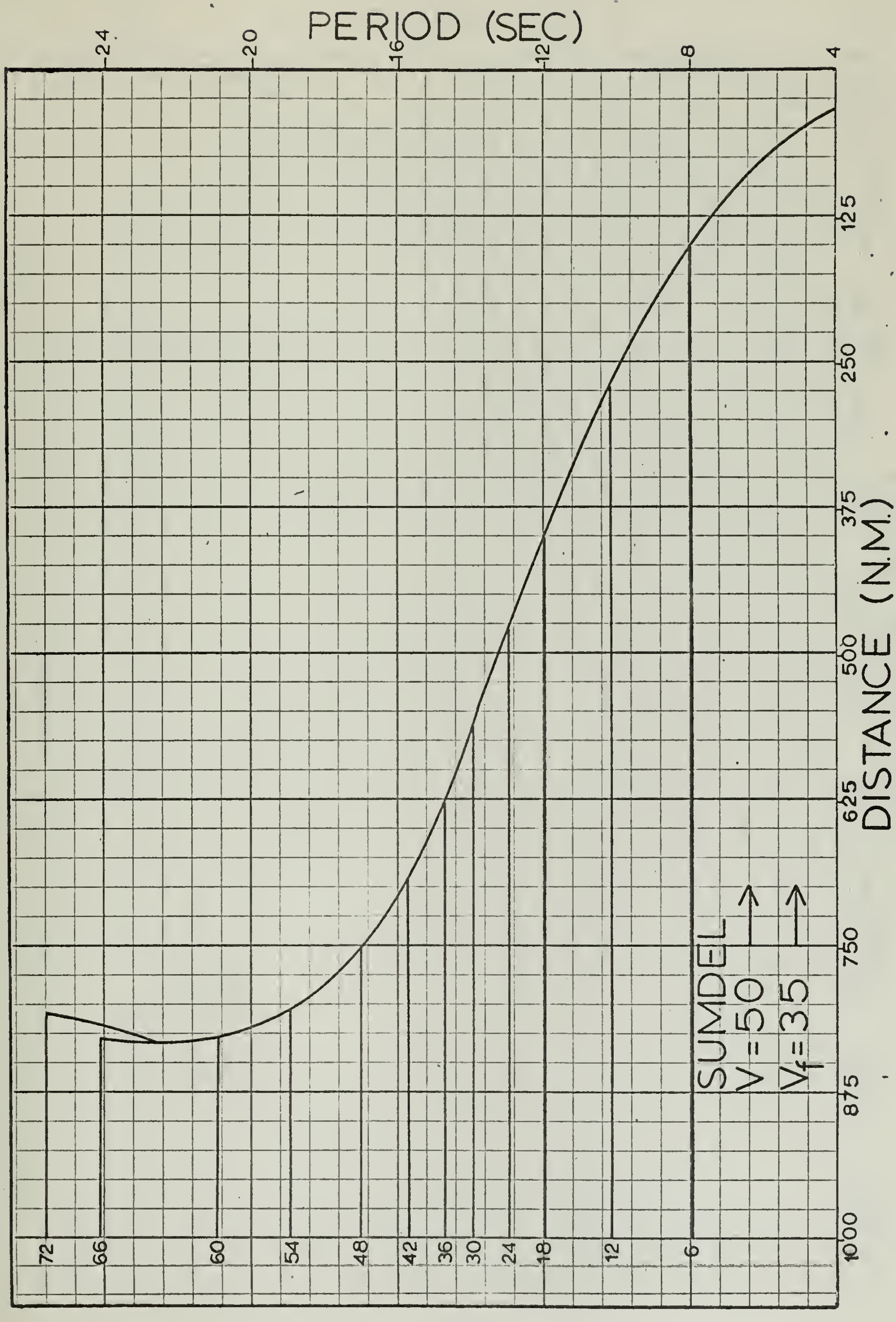
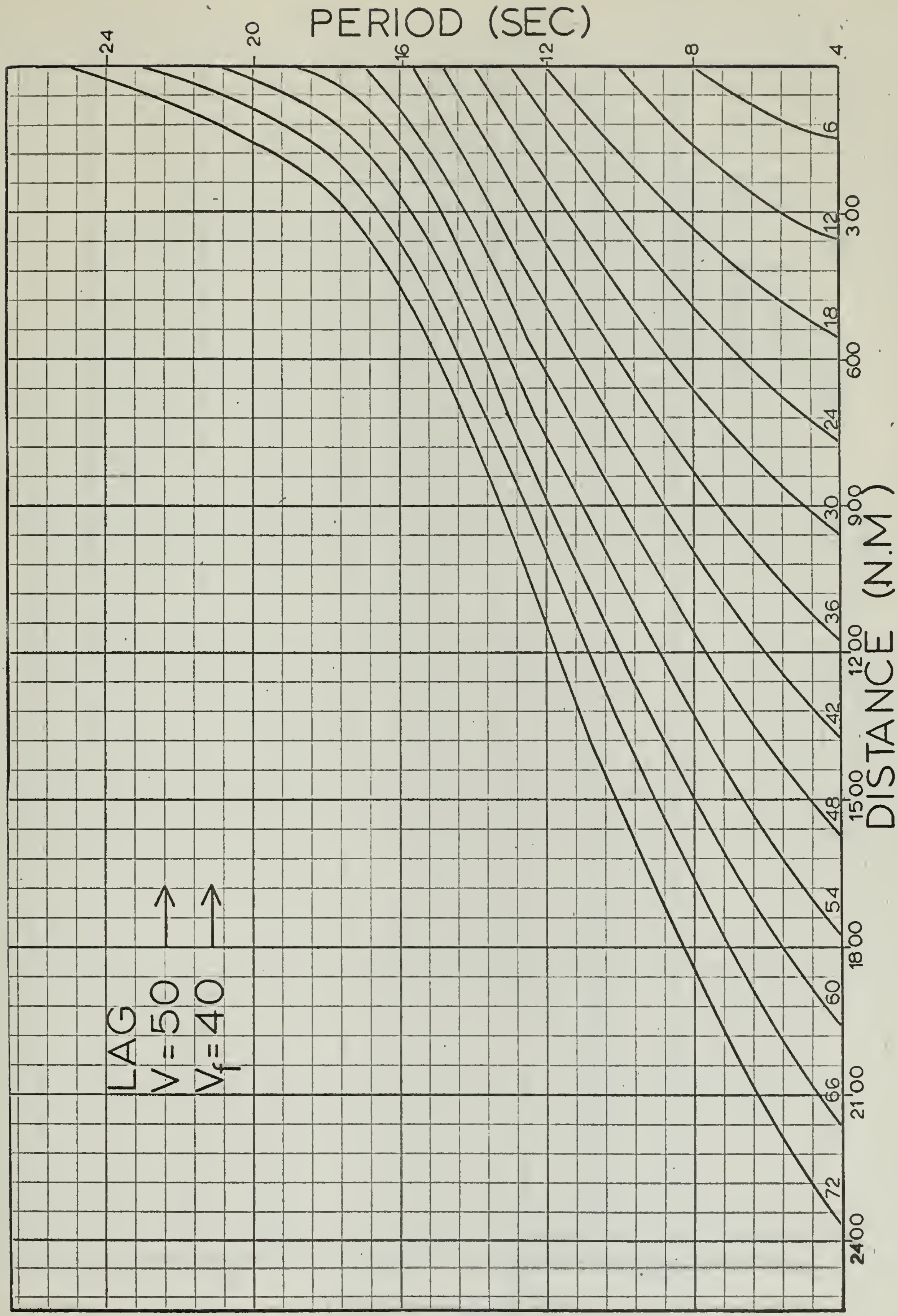
30
24
18
12
6

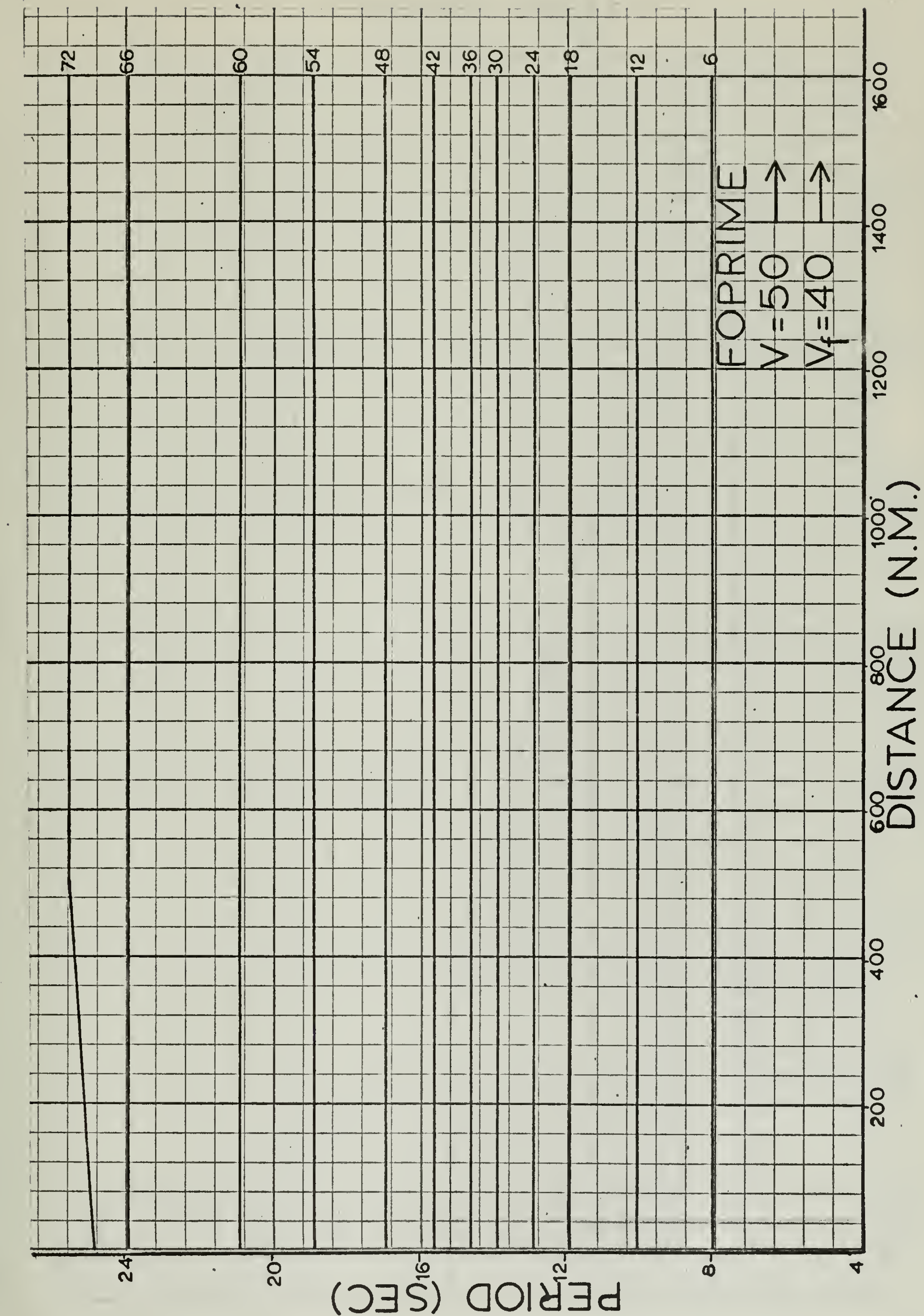

PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
75
150
225
300
375
450
525
600
72
66
60
54
48
42
36
30
24
18
12
6
SUMDEL
V = 50
Vf = 30

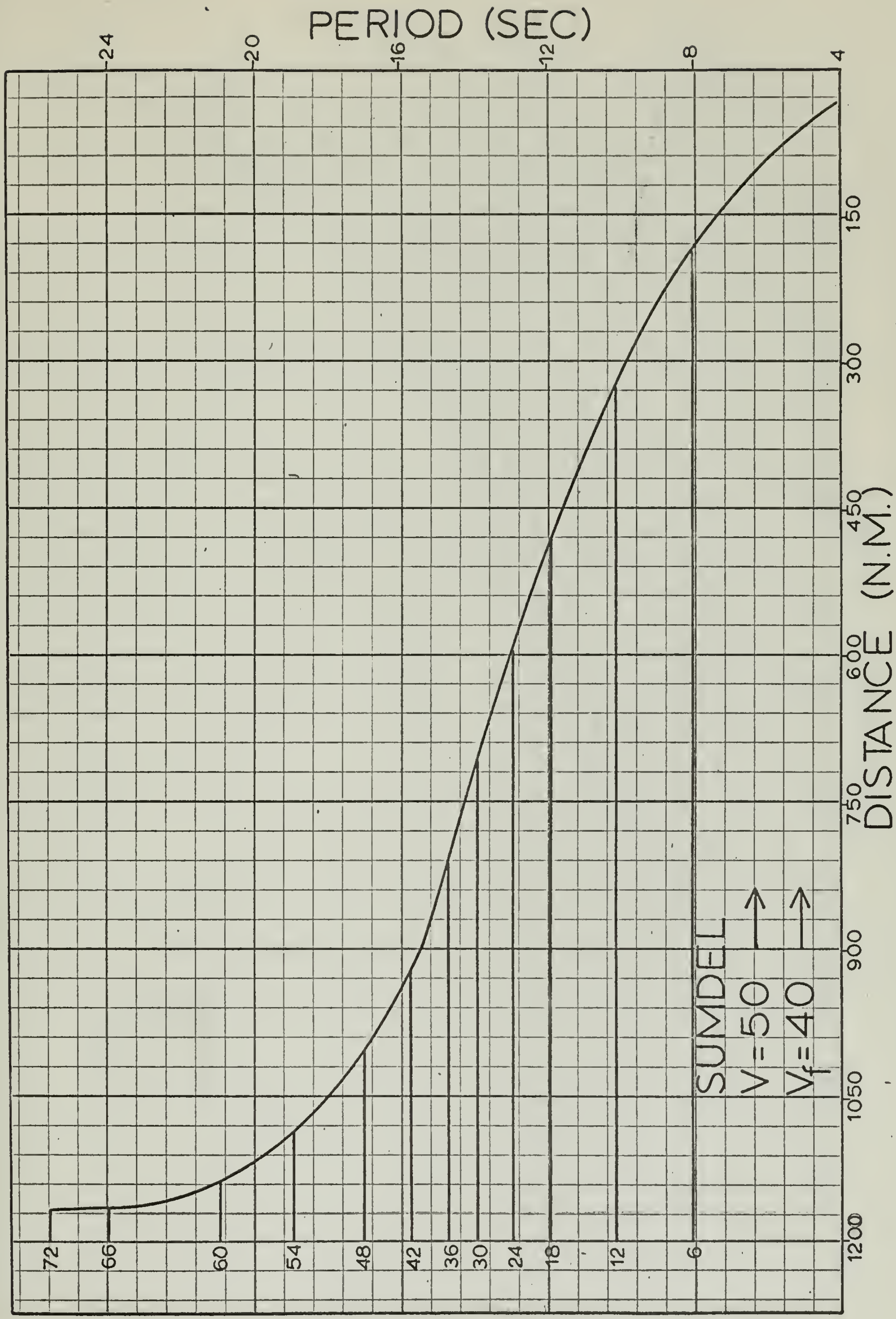

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
250
500
750
1000
1250
1500
1750
2000
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 50
Vf = 35

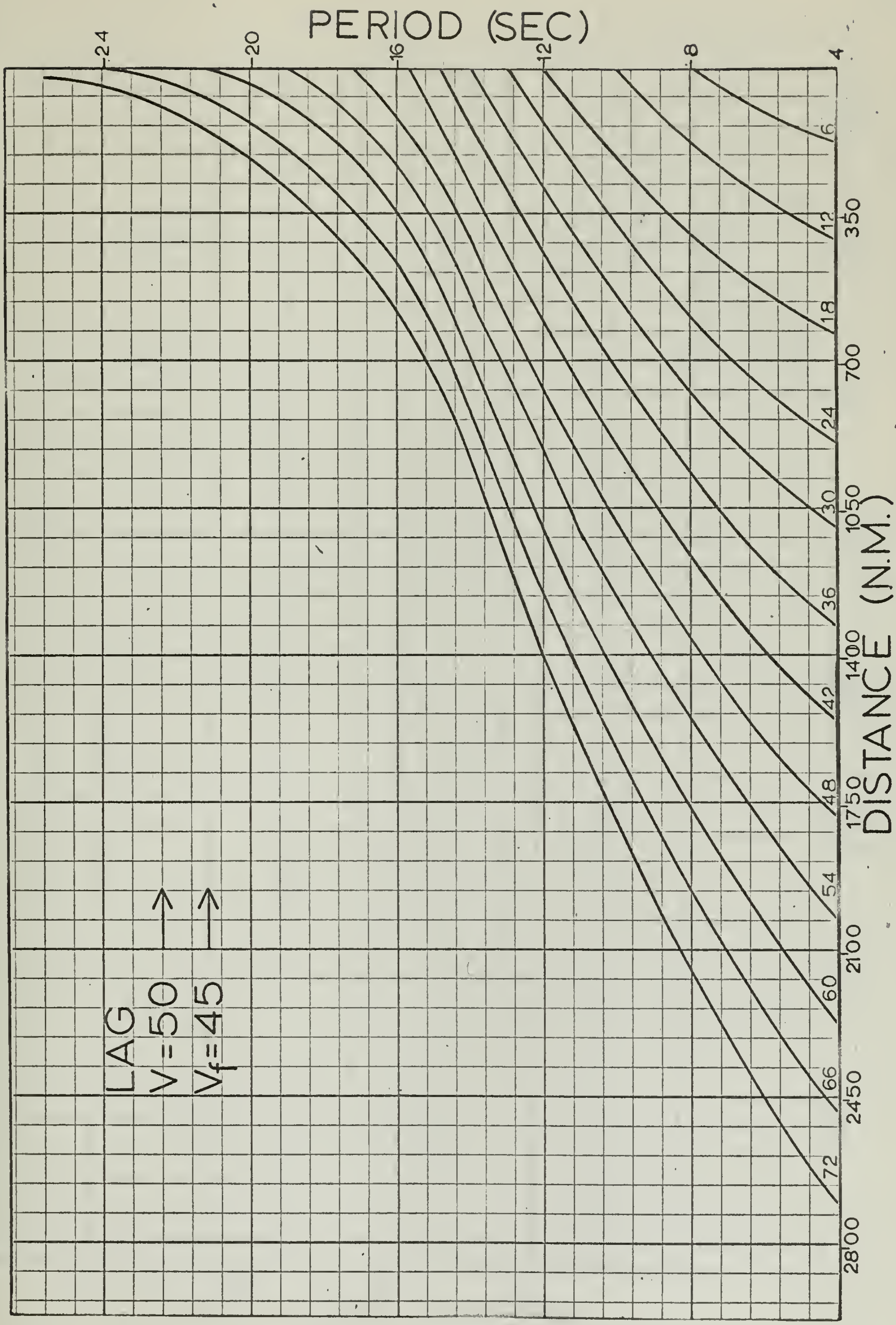

FOPRIME
V = 50
V_f = 35
PERIOD (SEC)
DISTANCE (N.M.)
72
66
60
54
48
42
36
30
24
18
12
6
24
20
16
12
8
4
200
400
600
800
1000
1200
1400
1600


PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
125
250
375
500
625
750
875
1000
72
66
60
54
48
42
36
30
24
18
12
6
SUMDEL
V = 50
$V_f$ = 35


PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M)
300
600
900
1200
1500
1800
2100
2400
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 50
V_f = 40


FOPRIME
V = 50
Vf = 40
DISTANCE (N.M.)
PERIOD (SEC)
200
400
600
800
1000
1200
1400
1600
4
8
12
16
20
24
72
66
60
54
48
42
36
30
24
18
12
6


PERIOD (SEC)
24
20
16
12
8
4
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)
SUMDEL
V = 50
Vf = 40
72
66
60
54
48
42
36
30
24
18
12
6


PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
350
700
1050
1400
1750
2100
2450
2800
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24
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42
48
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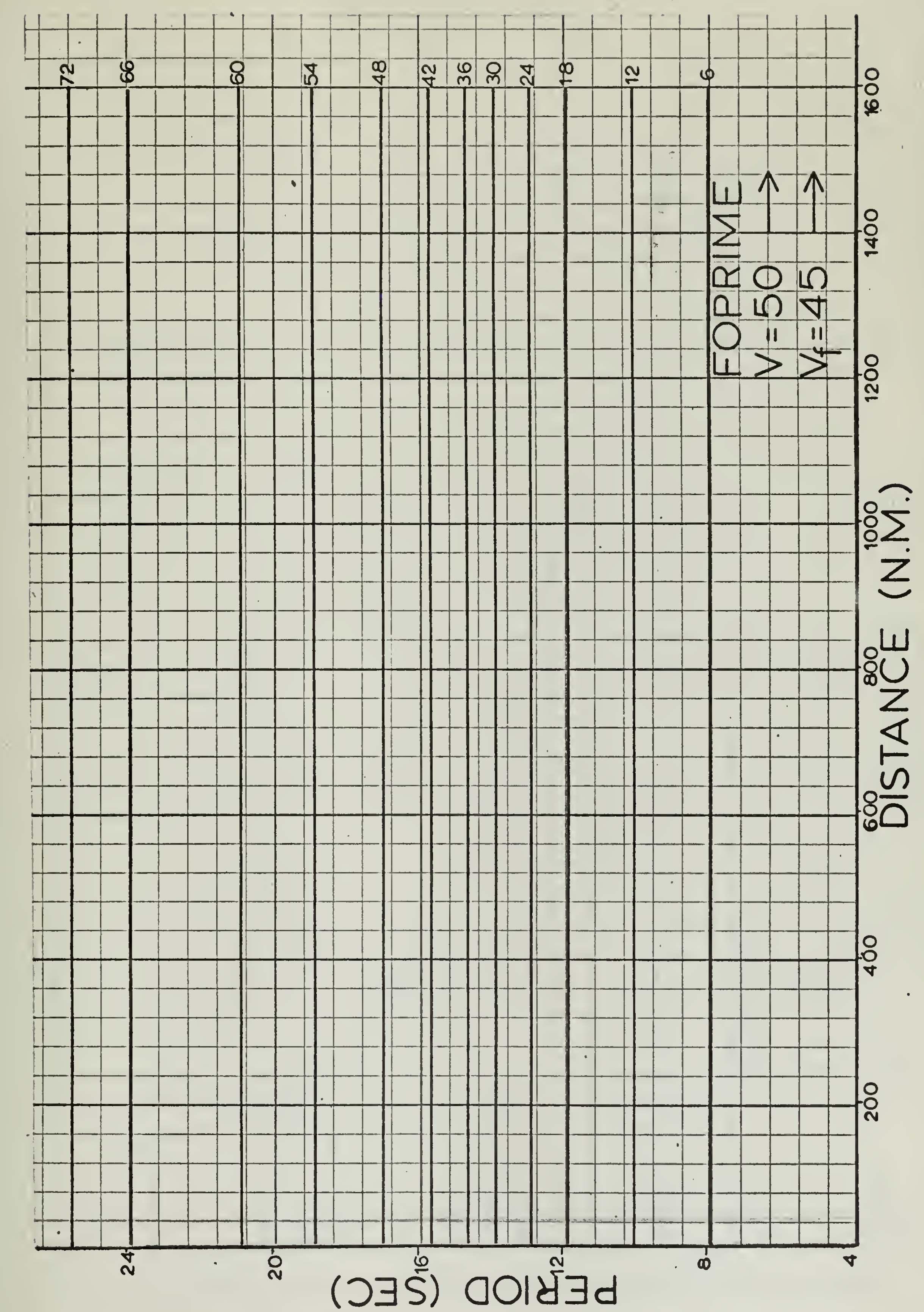
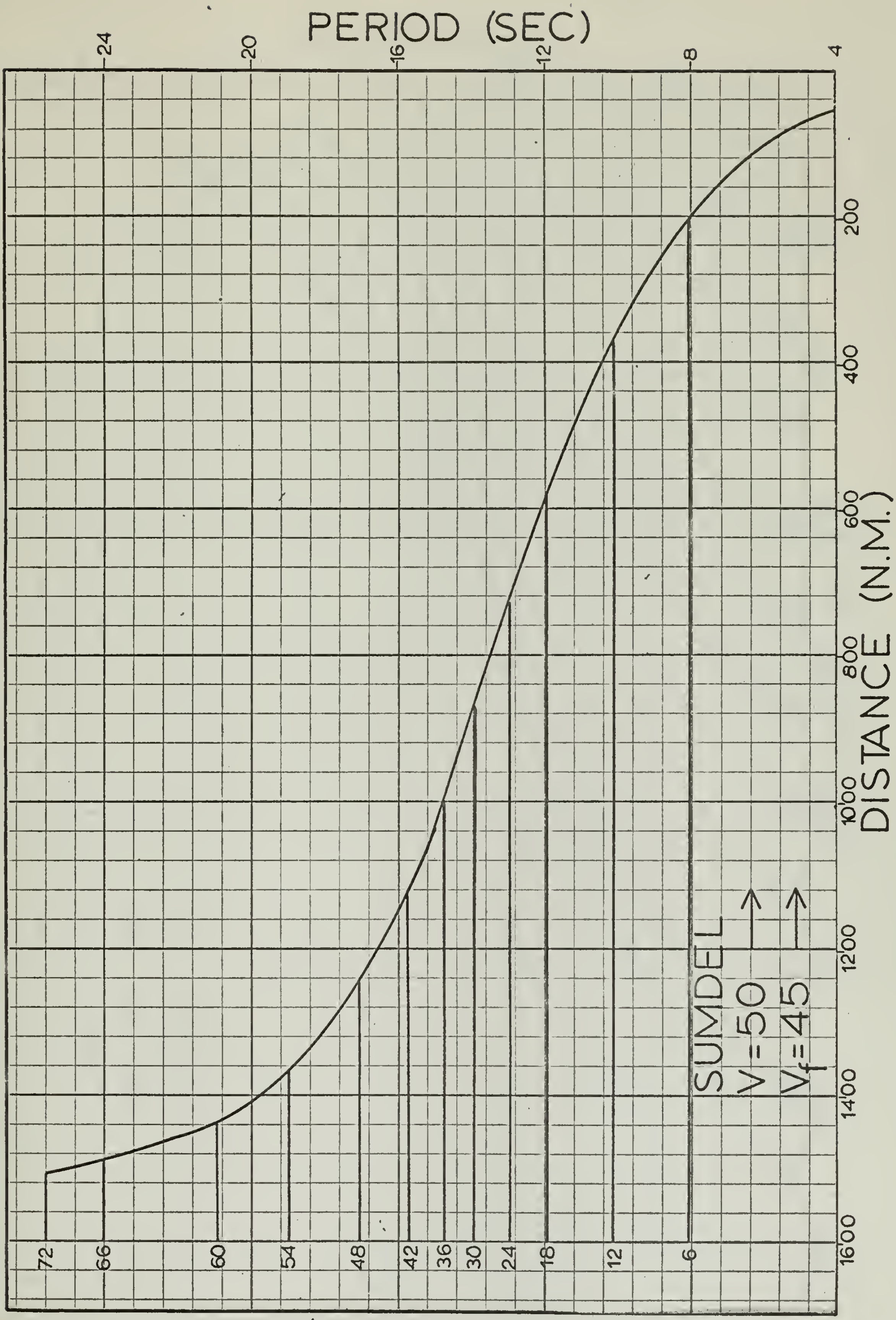
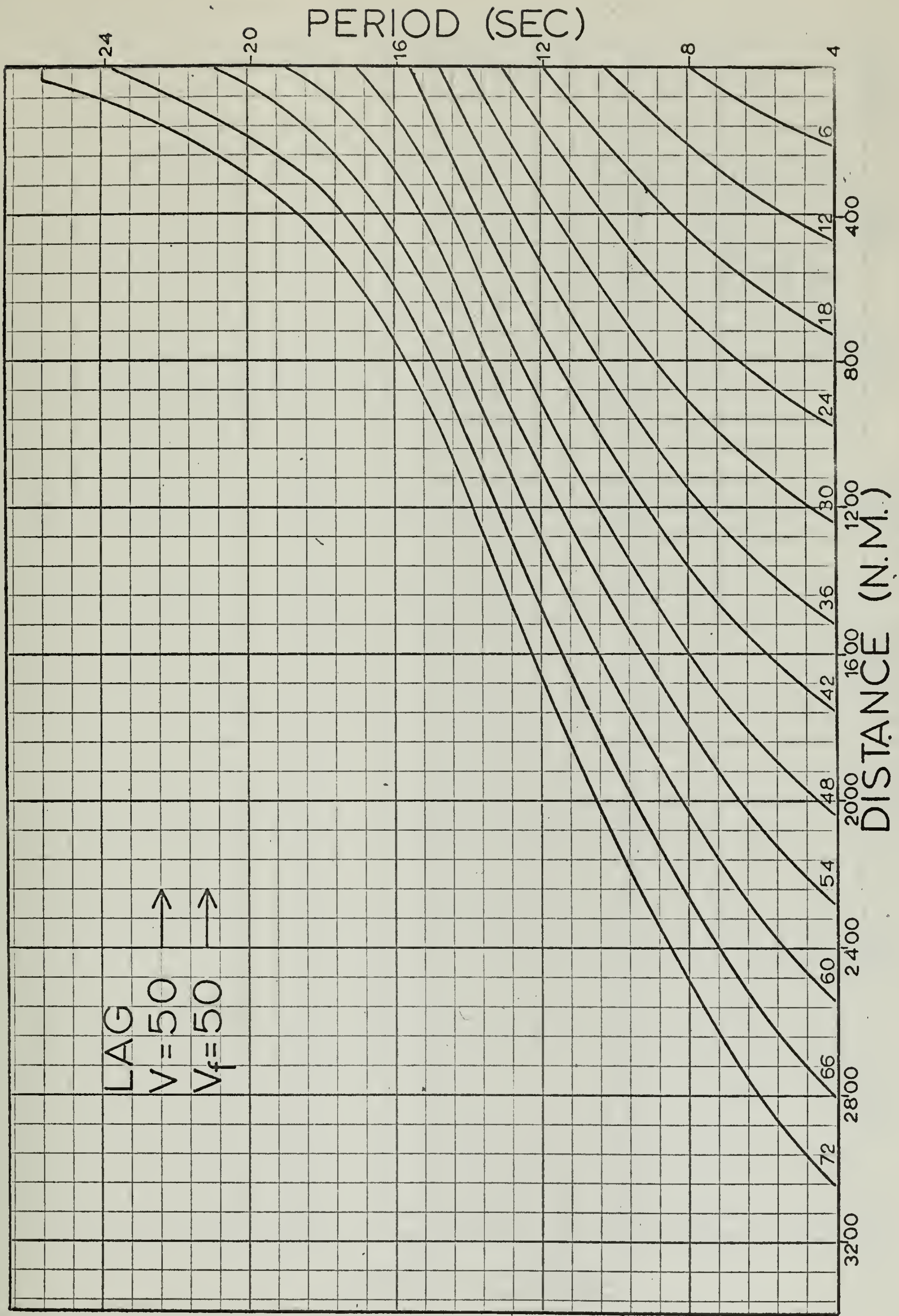
66
72
LAG
V = 50
V_f = 45

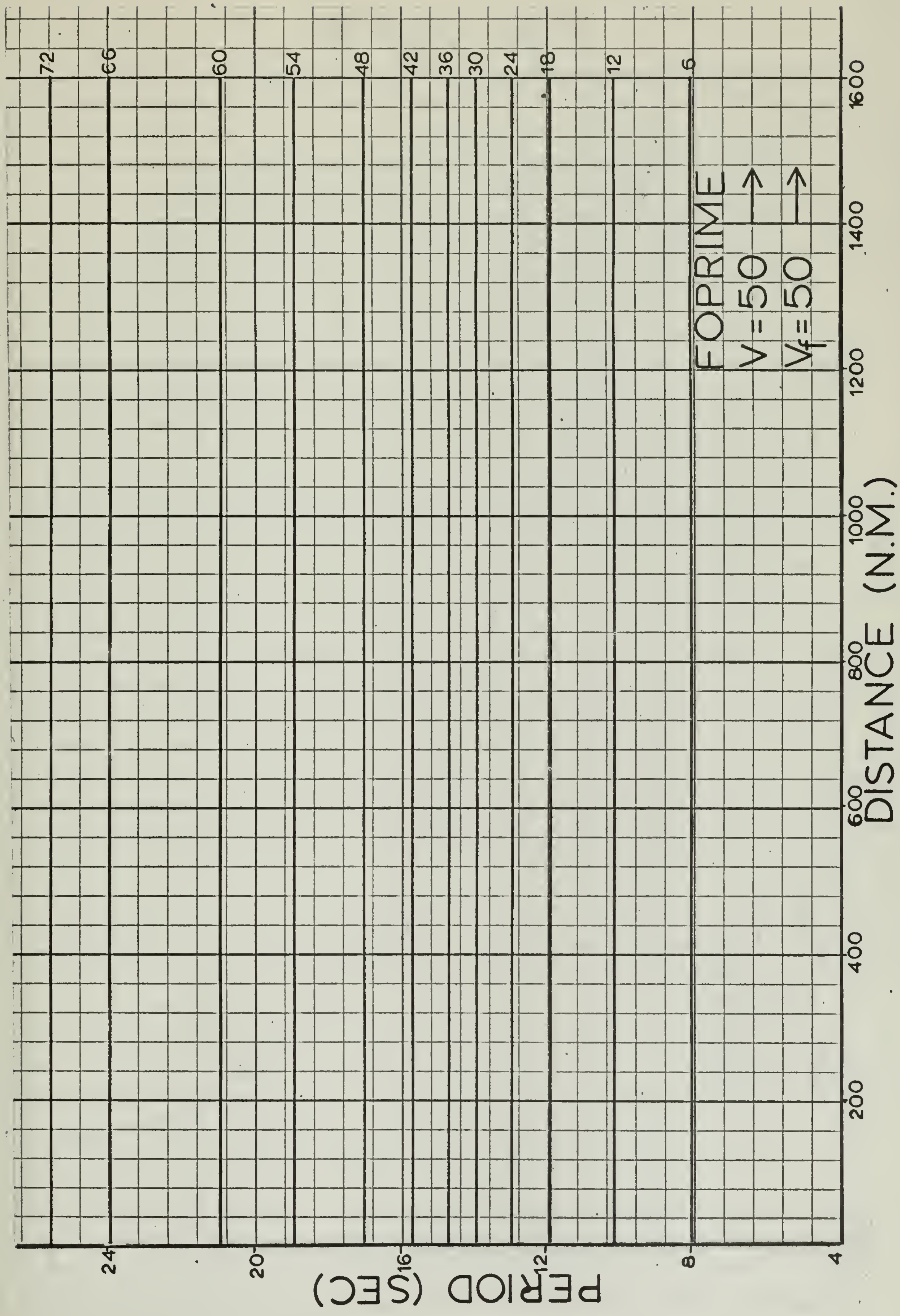

FOPRIME
V = 50
V_f = 45
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
PERIOD (SEC)
4
8
12
16
20
24
6
12
18
24
30
36
42
48
54
60
66
72

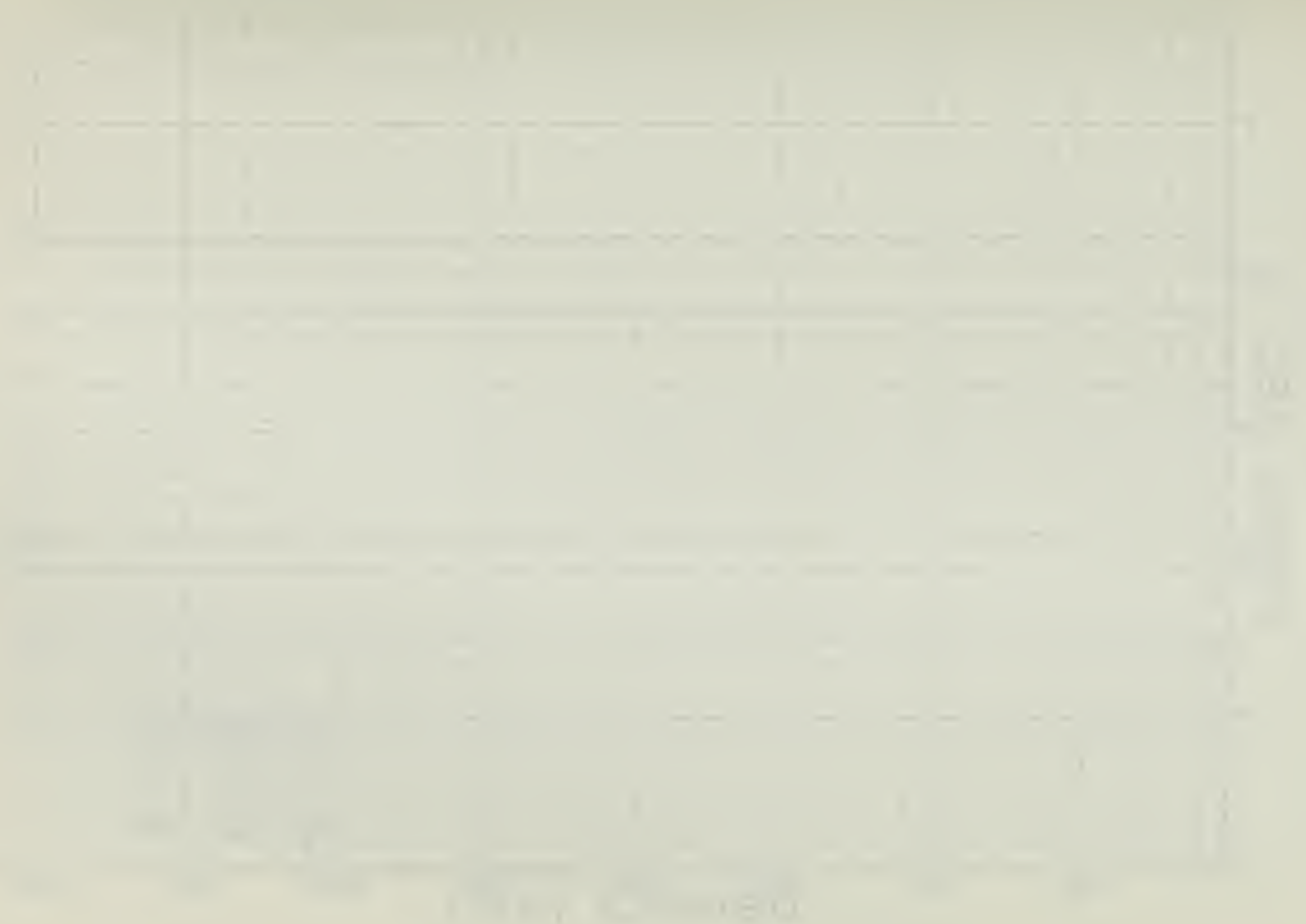


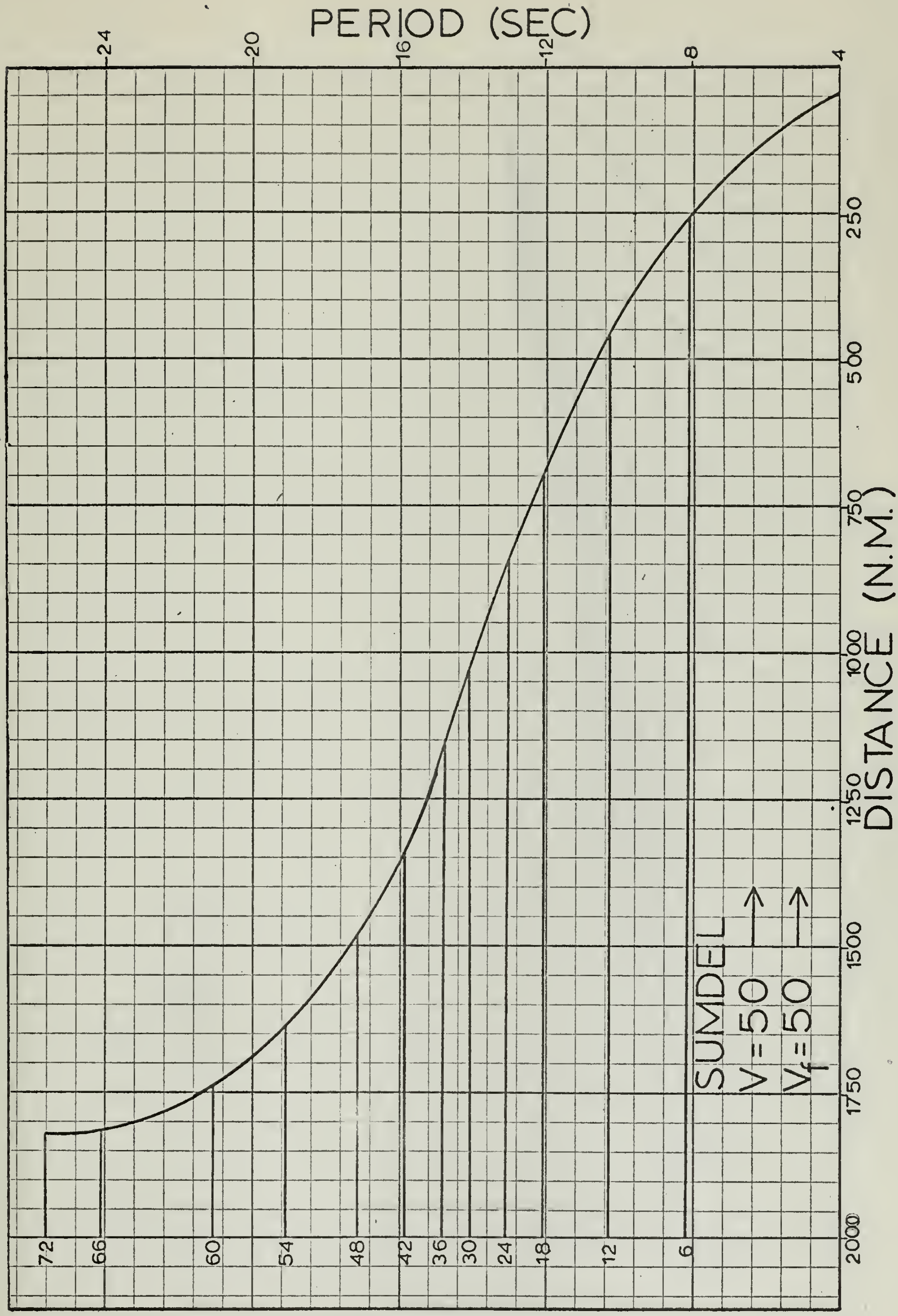
PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
SUMDEL
V = 50
$V_f$ = 45
72
66
60
54
48
42
36
30
24
18
12
6

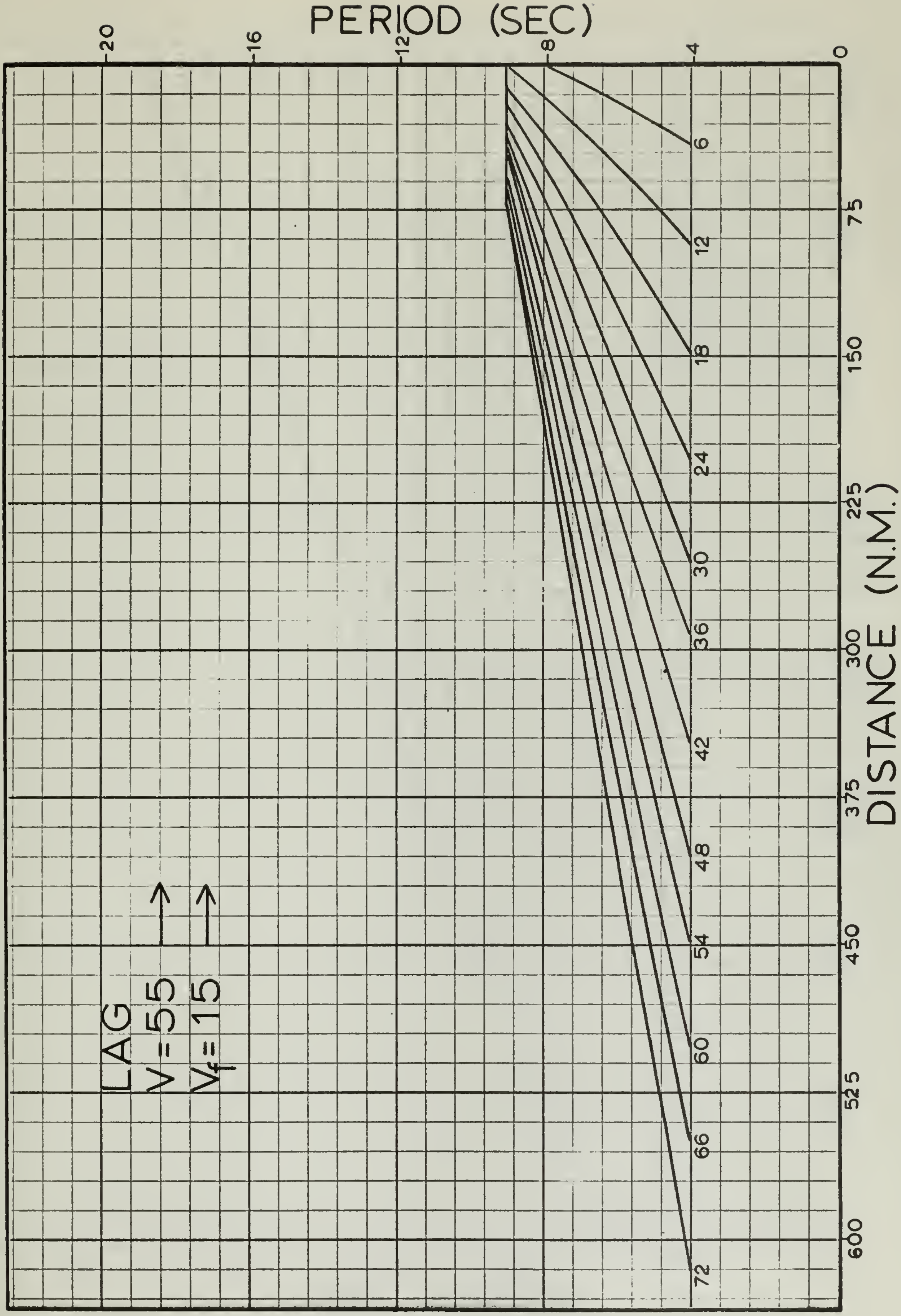


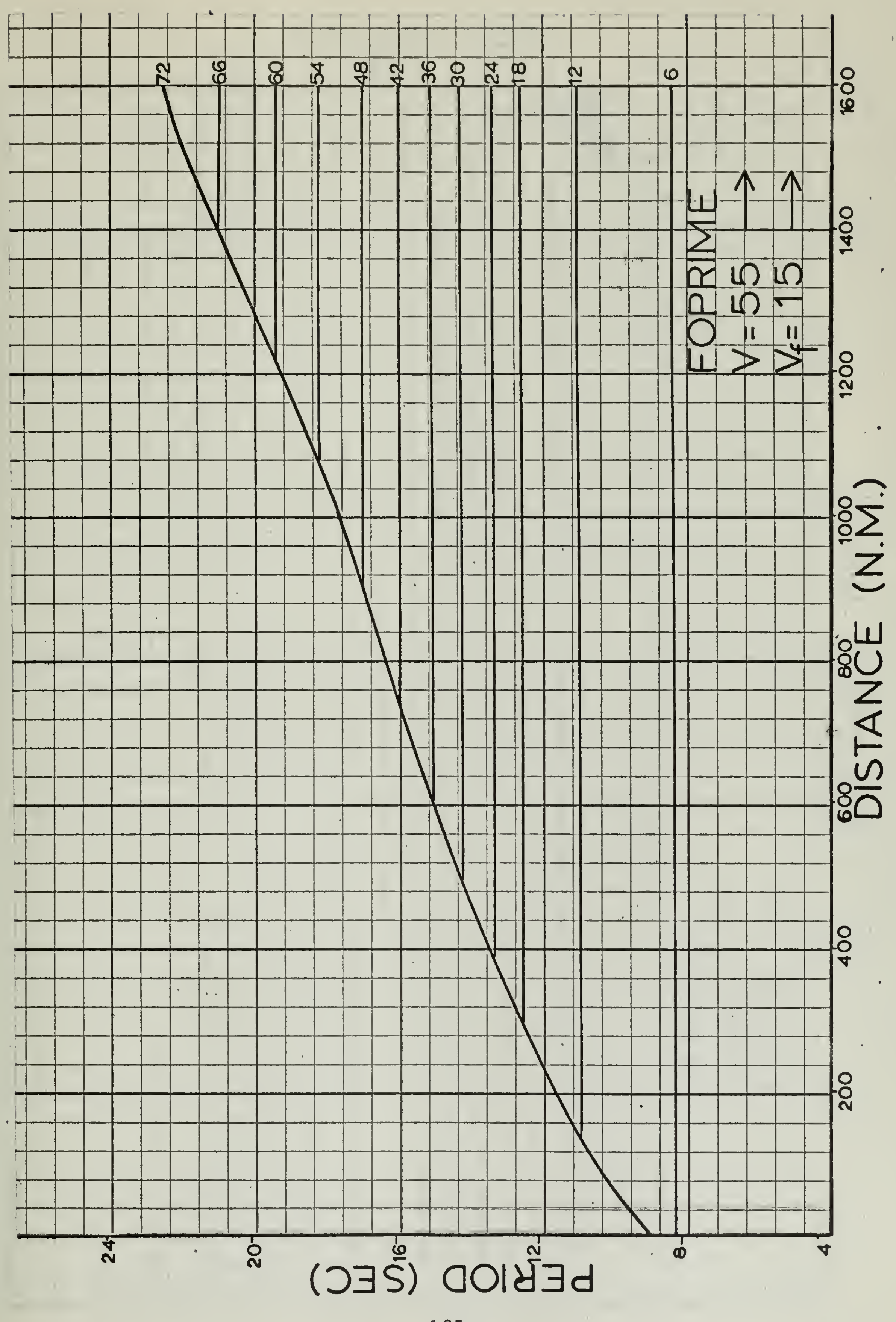
PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
400
800
1200
1600
2000
2400
2800
3200
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 50
V_f = 50

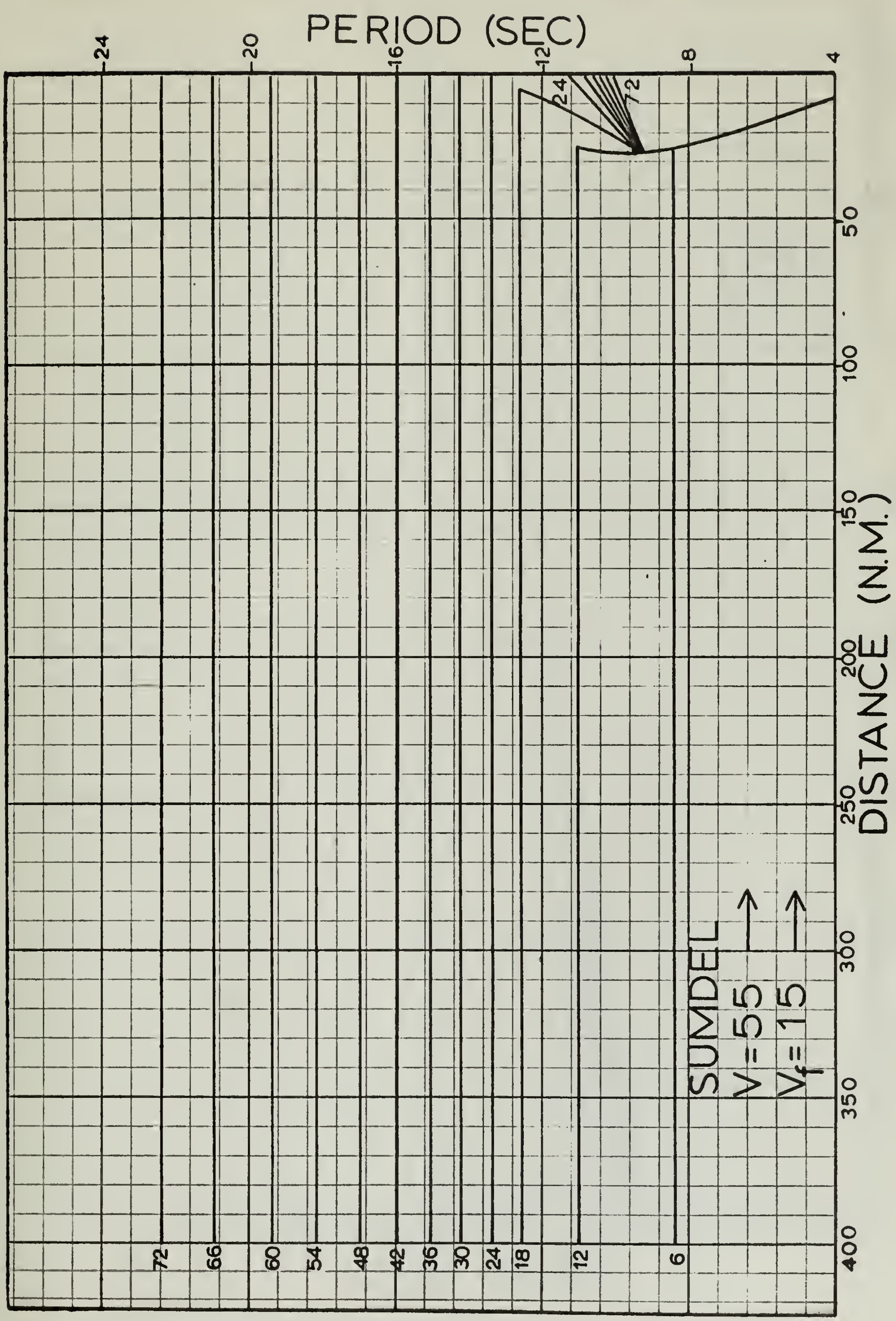

FOPRIME
V = 50 →
$V_f$ = 50 →
DISTANCE (N.M.)
PERIOD (SEC)
200
400
600
800
1000
1200
1400
1600
4
8
12
16
20
24
72
66
60
54
48
42
36
30
24
18
12
6



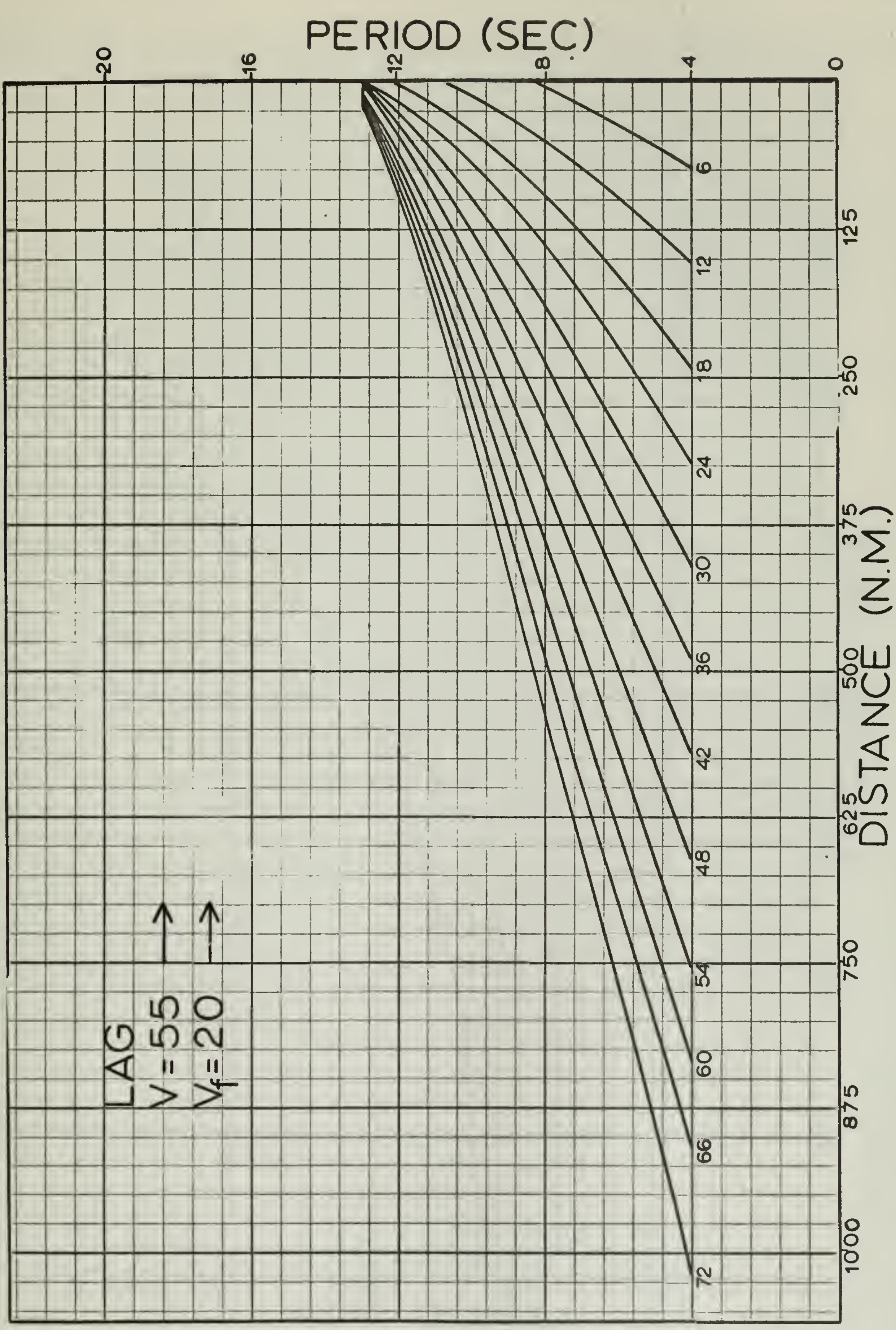

PERIOD (SEC)
24
20
16
12
8
4
250
500
750
1000
1250
1500
1750
2000
DISTANCE (N.M.)
SUMDEL
V = 50
$V_f$ = 50
72
66
60
54
48
42
36
30
24
18
12
6

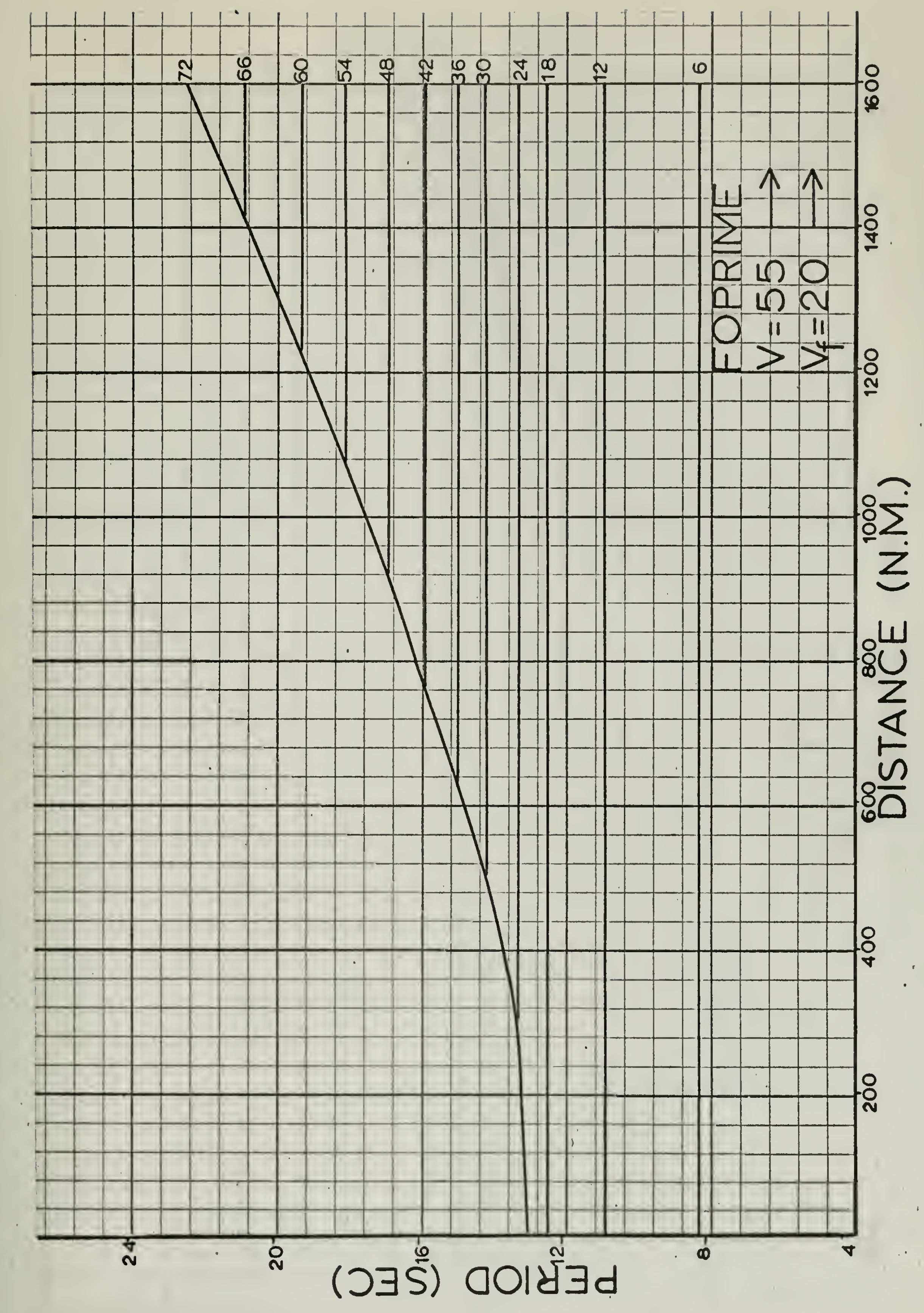

PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
75
150
225
300
375
450
525
600
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 55
V_f = 15

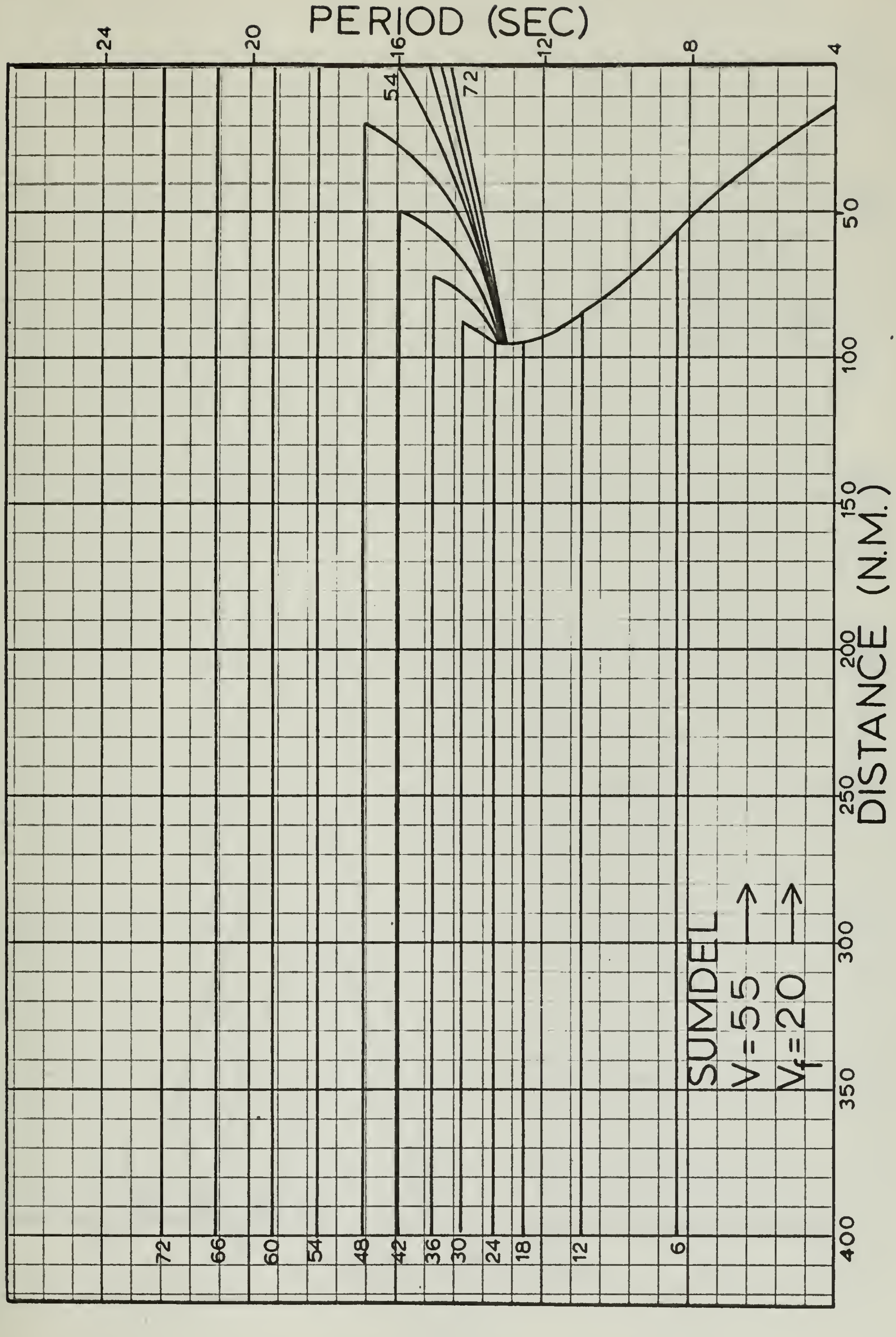

FOPRIME
V = 55
Vf = 15
DISTANCE (N.M.)
PERIOD (SEC)
4
8
12
16
20
24
200
400
600
800
1000
1200
1400
1600
6
12
18
24
30
36
42
48
54
60
66
72

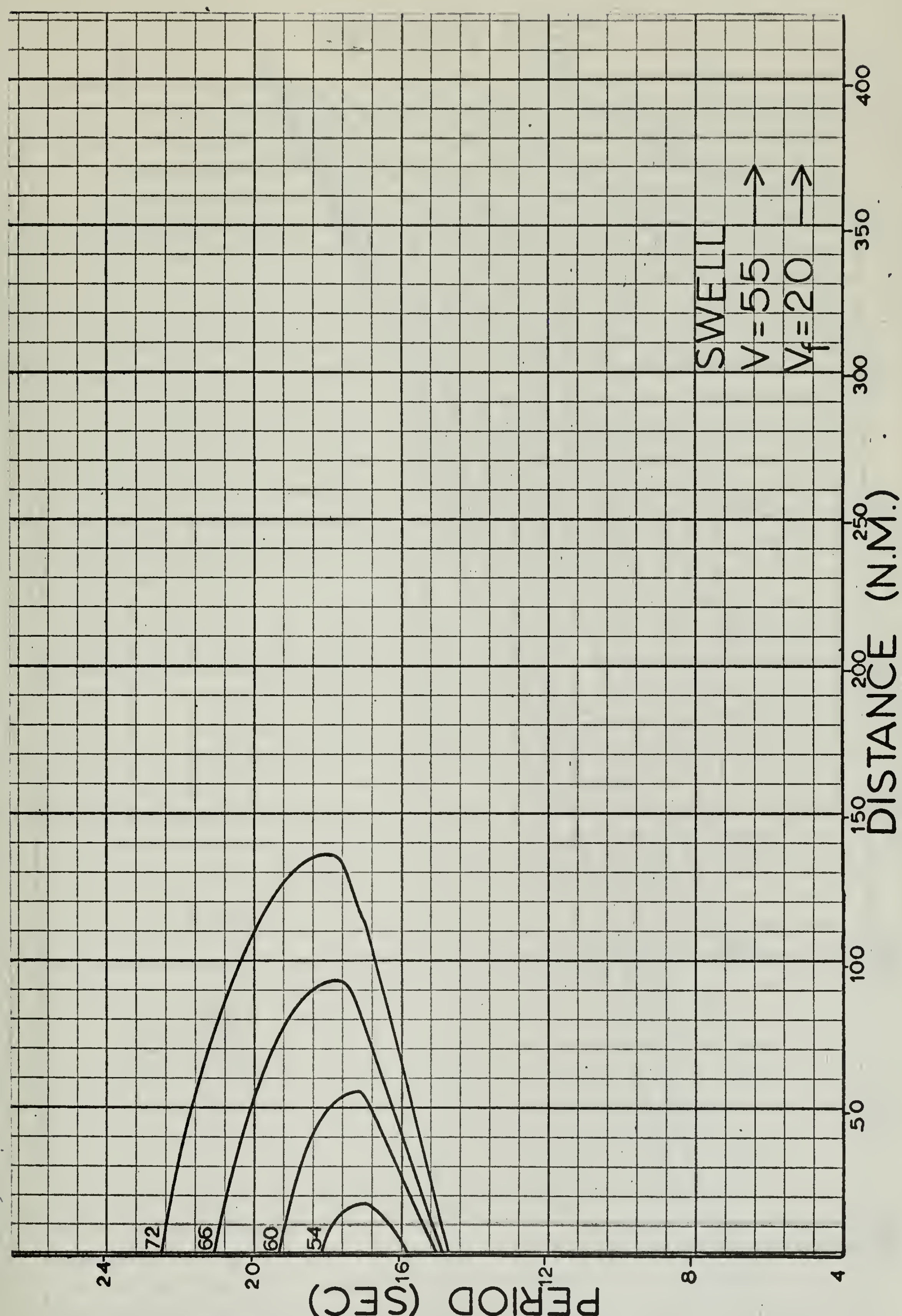

PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
50
100
150
200
250
300
350
400
72
66
60
54
48
42
36
30
24
18
12
6
24
72
SUMDEL
V = 55
V_f = 15

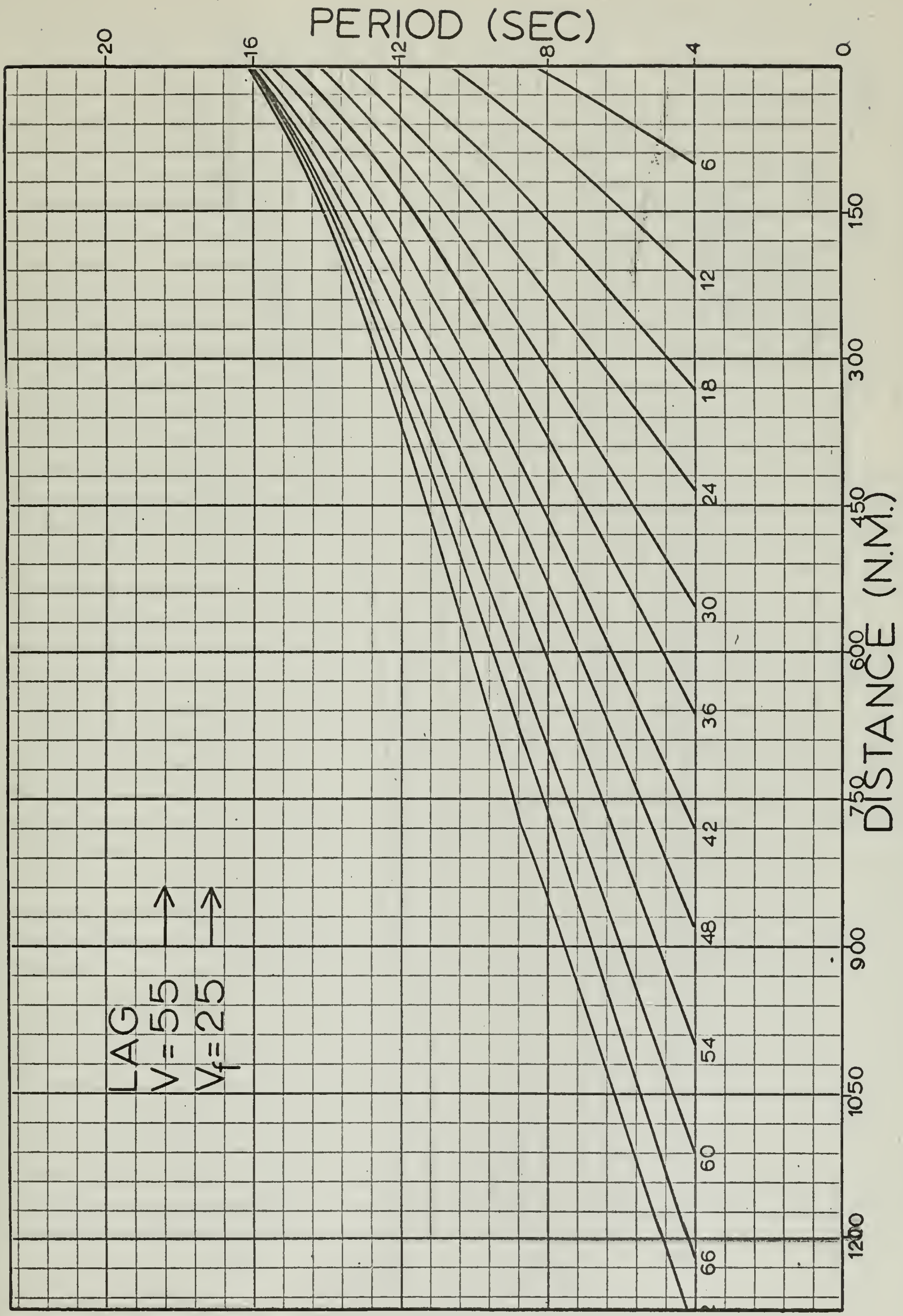

PERIOD (SEC)
DISTANCE (N.M.)
SWELL
V = 55
V_f = 15
24
20
16
12
8
4
50
100
150
200
250
300
350
400
72
66
60
54
48
42
36
30
24


PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
125
250
375
500
625
750
875
1000
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 55
Vf = 20

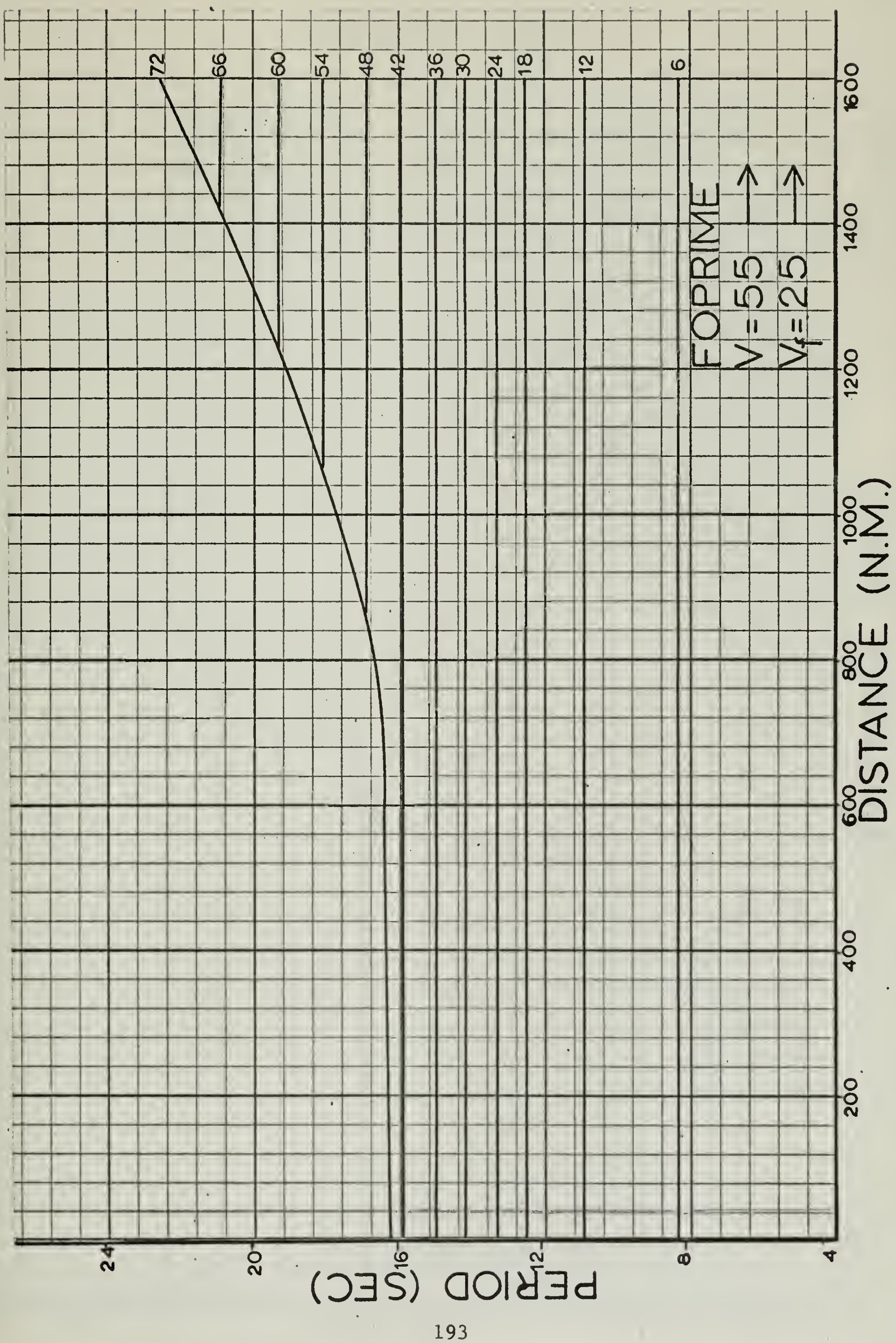

FOPRIME
V = 55
$V_f$ = 20
DISTANCE (N.M.)
PERIOD (SEC)
200
400
600
800
1000
1200
1400
1600
4
8
12
16
20
24
6
12
18
24
30
36
42
48
54
60
66
72


PERIOD (SEC)
24
20
16
12
8
4
54
72
DISTANCE (N.M.)
50
100
150
200
250
300
350
400
SUMDEL
V=55
Vf=20
72
66
60
54
48
42
36
30
24
18
12
6

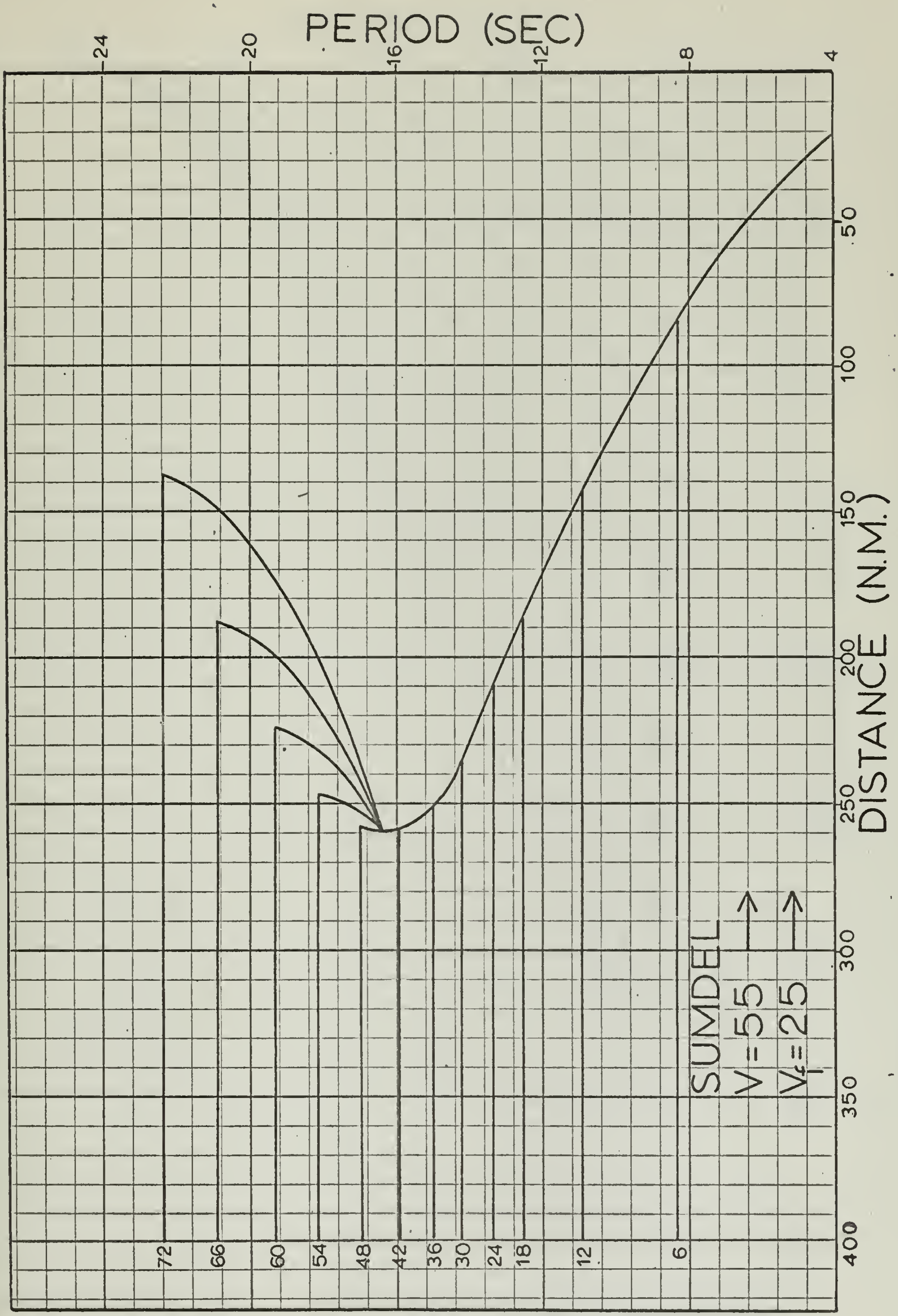

SWELL
V = 55
V_f = 20
DISTANCE (N.M.)
PERIOD (SEC)
50
100
150
200
250
300
350
400
4
8
12
16
20
24
54
60
66
72

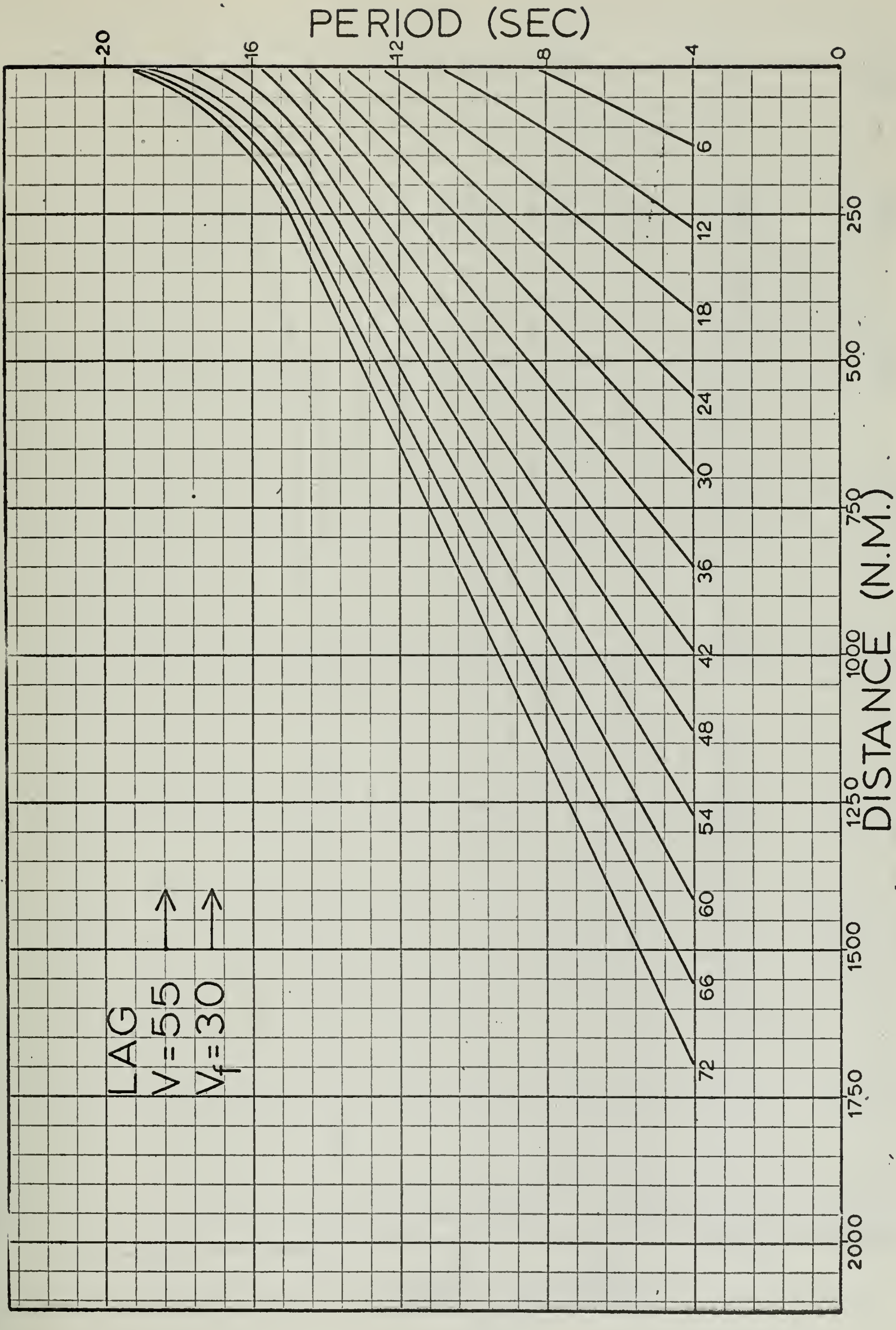


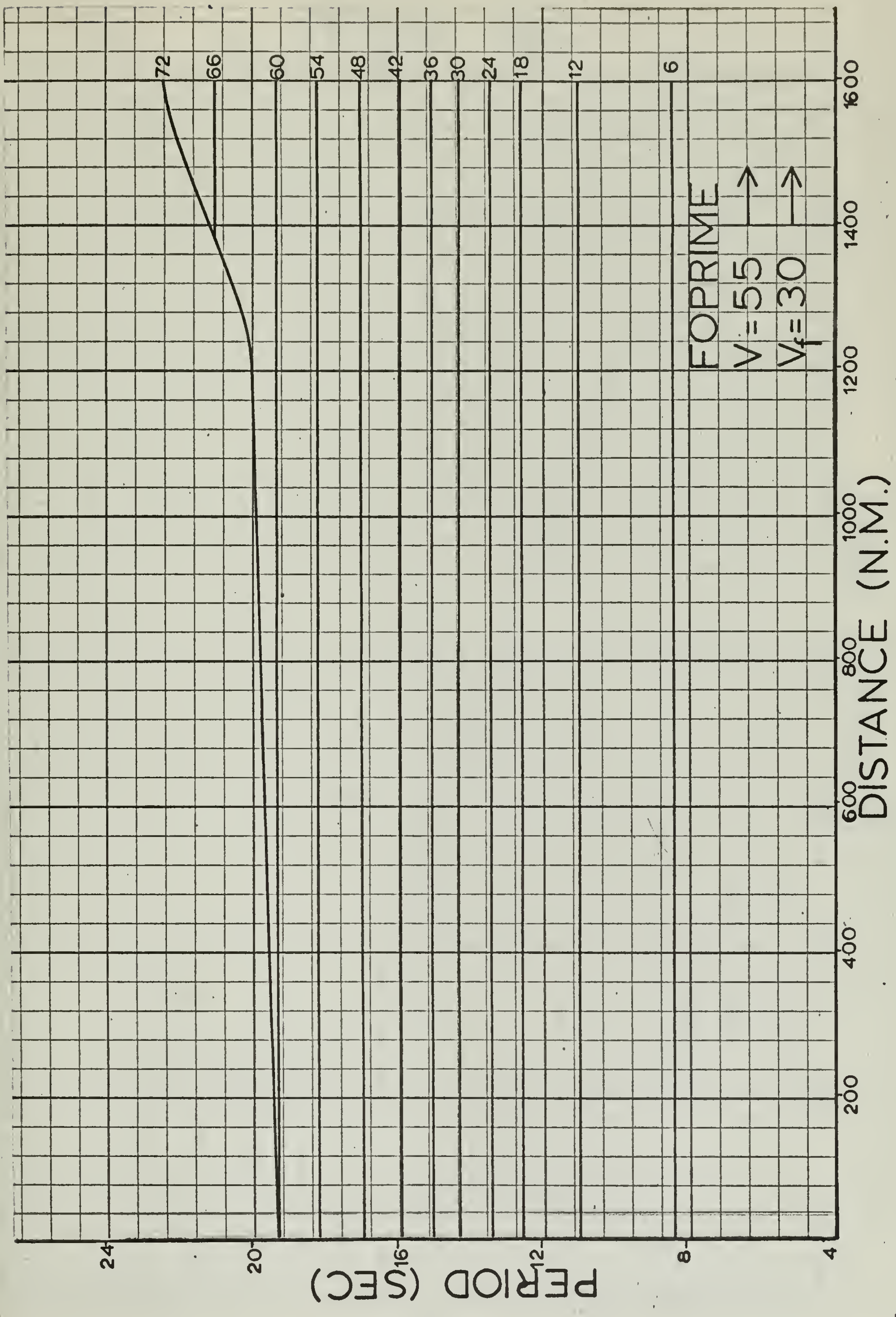
PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
150
300
450
600
750
900
1050
1200
6
12
18
24
30
36
42
48
54
60
66
LAG
V = 55
$V_f$ = 25

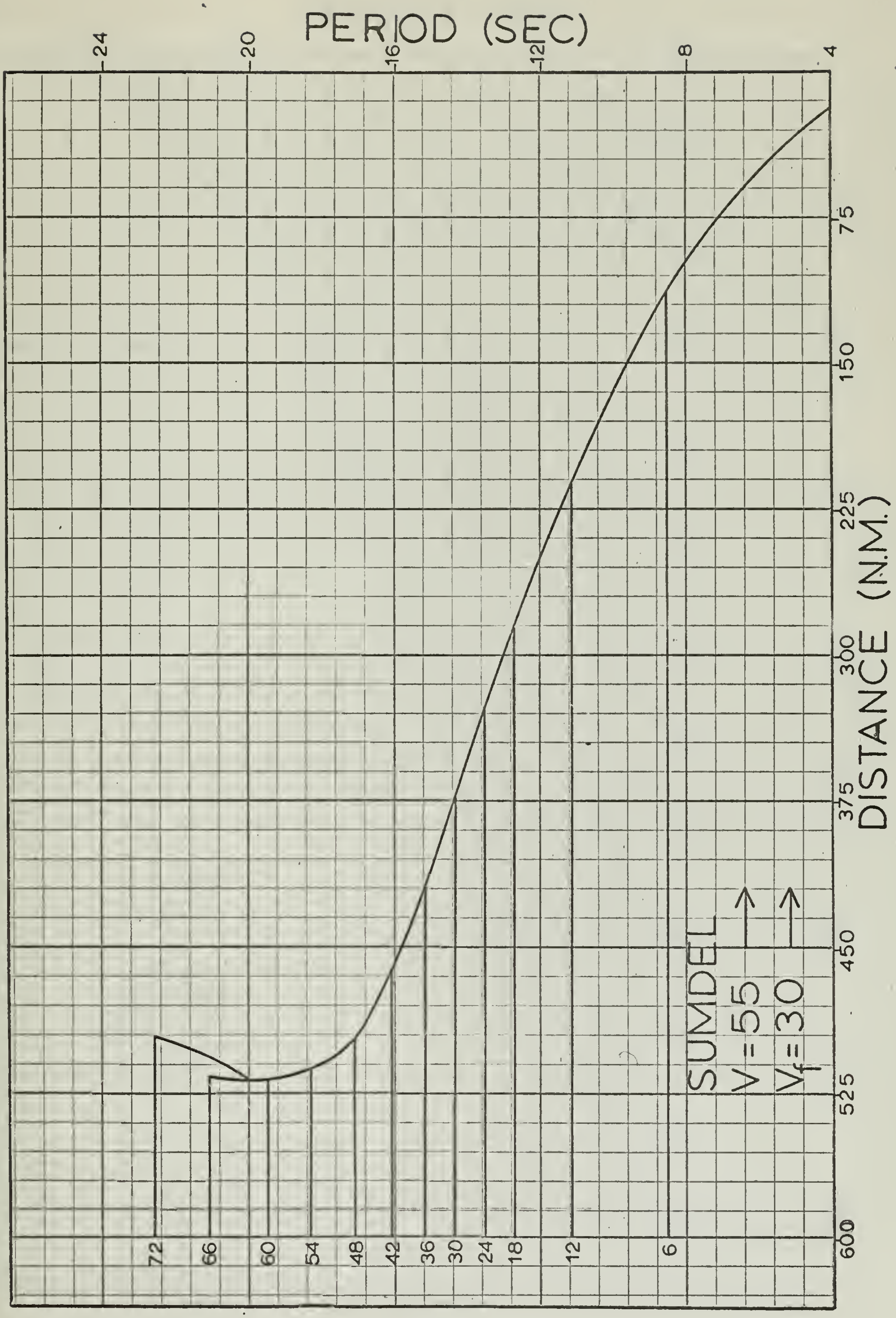


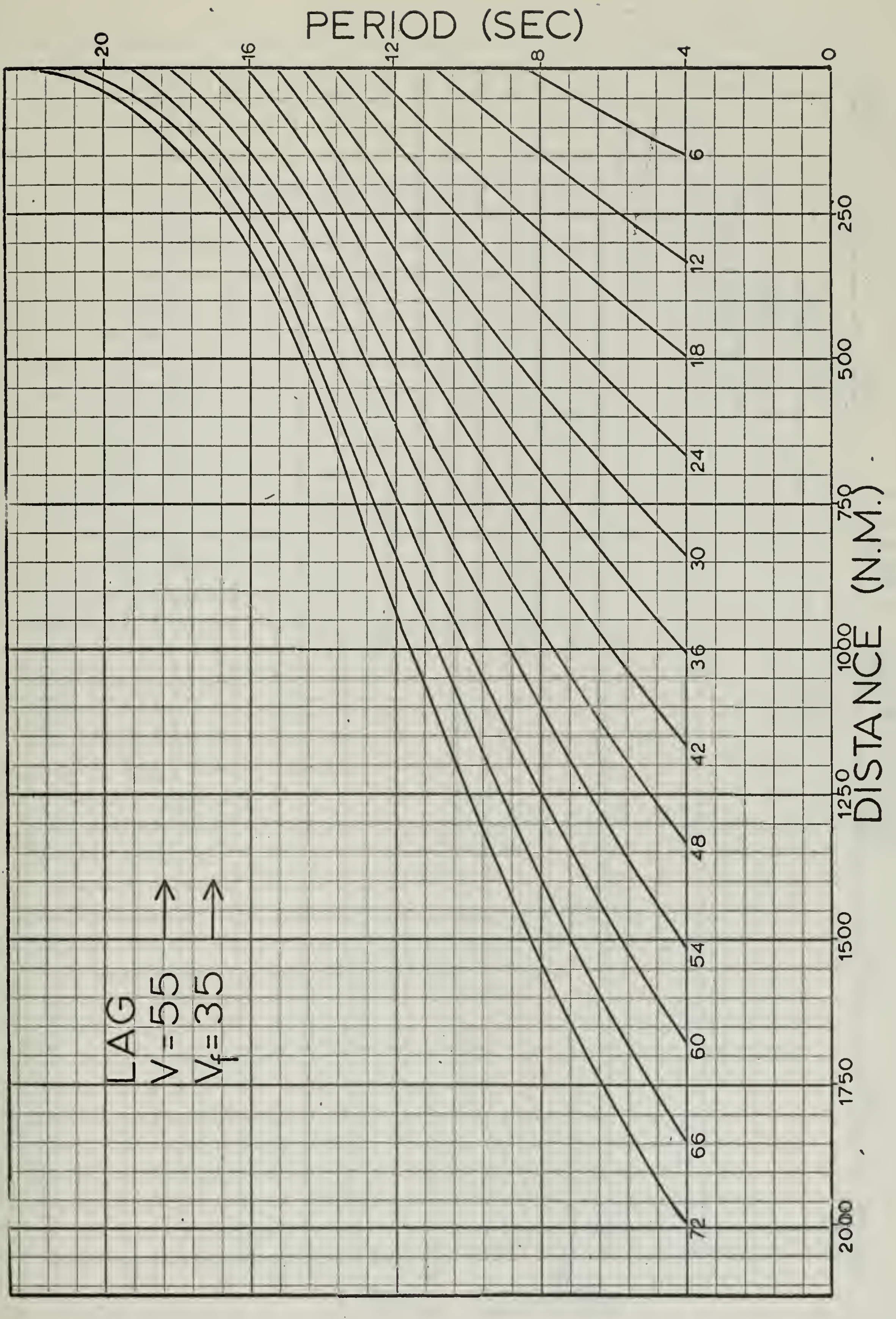
FOPRIME
V = 55
Vf = 25
DISTANCE (N.M.)
PERIOD (SEC)
200
400
600
800
1000
1200
1400
1600
4
8
12
16
20
24
6
12
18
24
30
36
42
48
54
60
66
72

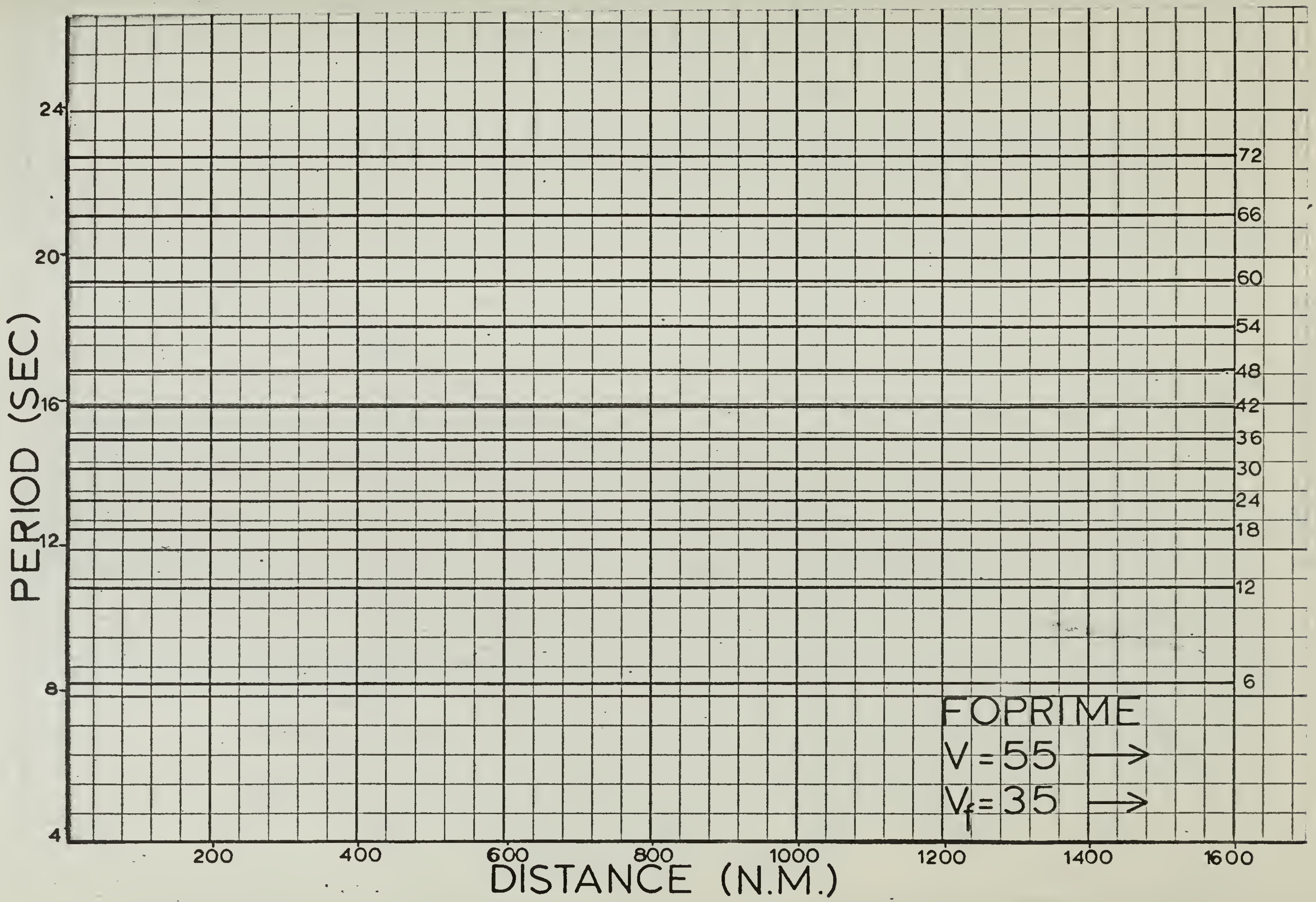

PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
50
100
150
200
250
300
350
400
SUMDEL
V = 55
V = 25
72
66
60
54
48
42
36
30
24
18
12
6


PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
250
500
750
1000
1250
1500
1750
2000
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 55
$V_f$ = 30

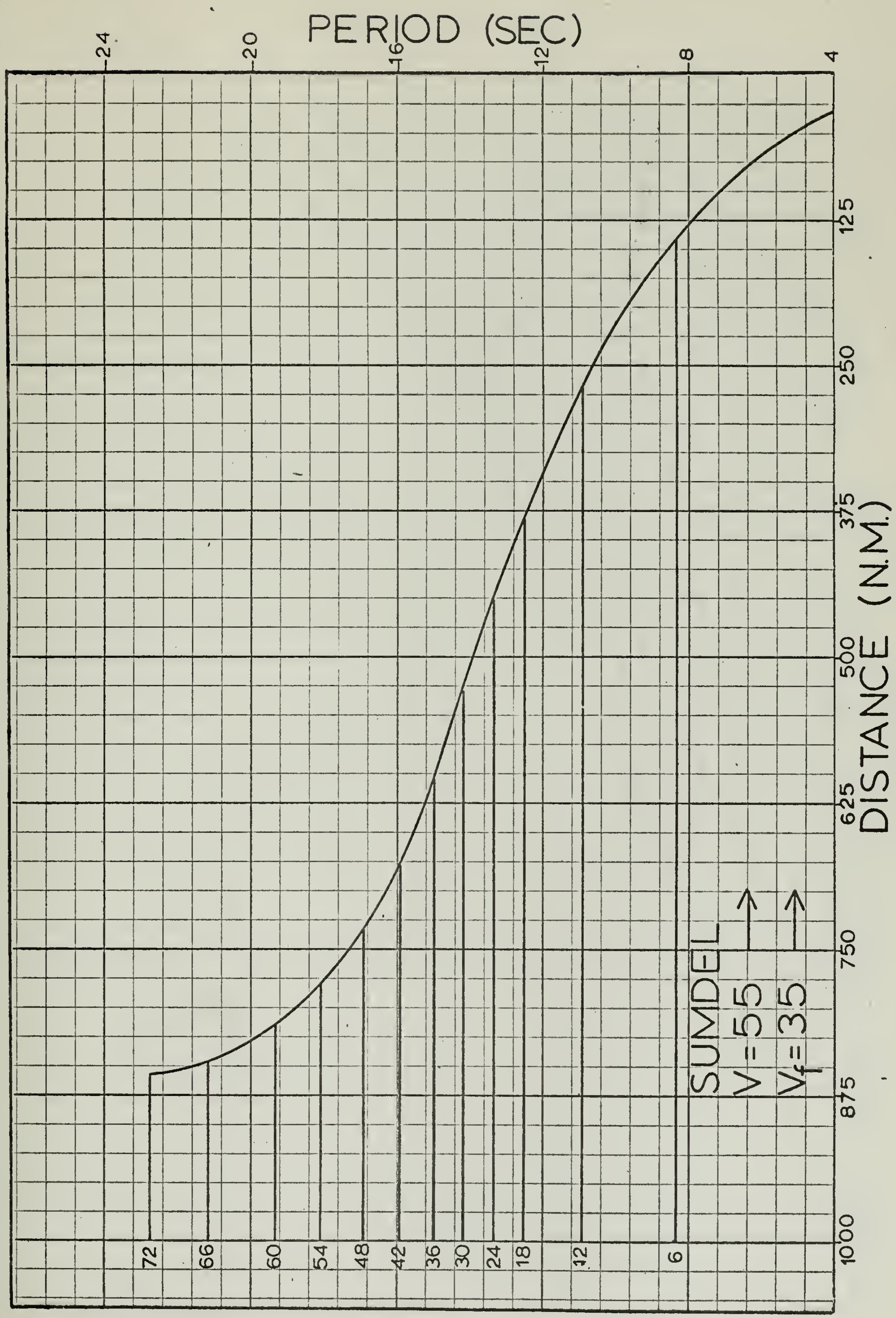

FOPRIME
V = 55
Vf = 30
DISTANCE (N.M.)
PERIOD (SEC)
72
66
60
54
48
42
36
30
24
18
12
6
200
400
600
800
1000
1200
1400
1600
24
20
16
12
8
4

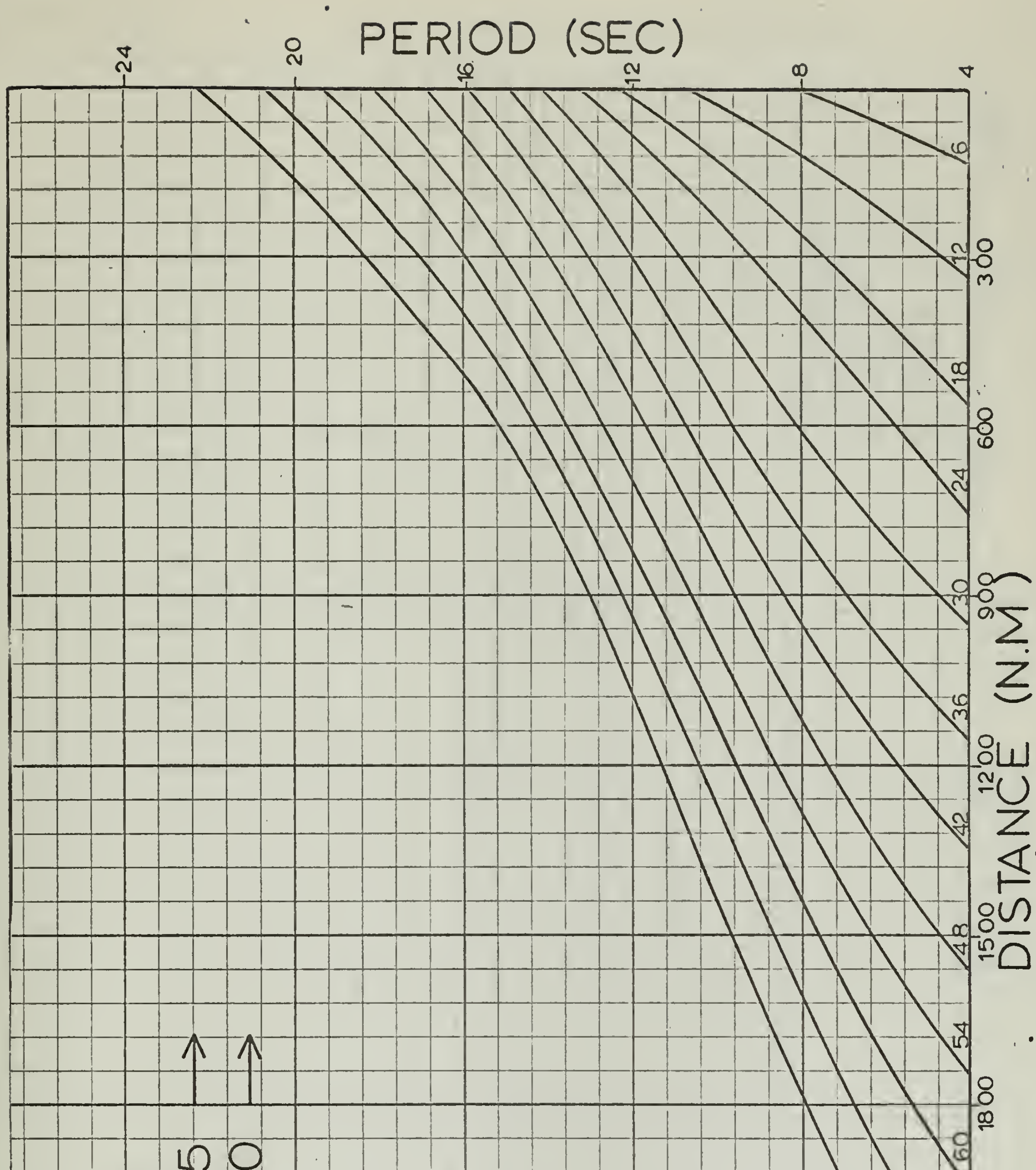

PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
75
150
225
300
375
450
525
600
72
66
60
54
48
42
36
30
24
18
12
6
SUMDEL
V = 55
$V_f$ = 30

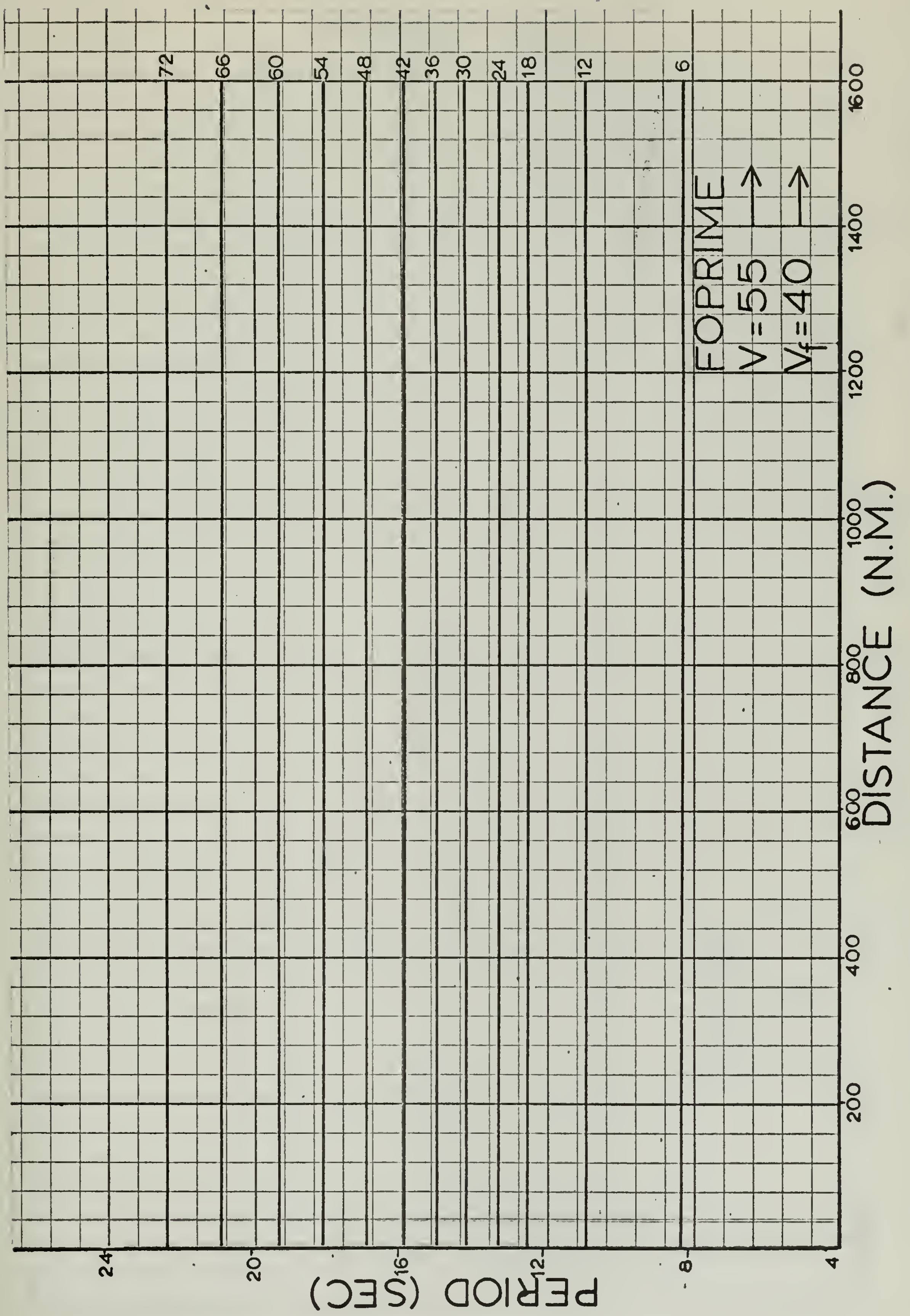

PERIOD (SEC)
20
16
12
8
4
0
250
500
750
1000
1250
1500
1750
2000
DISTANCE (N.M.)
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 55
V_f = 35

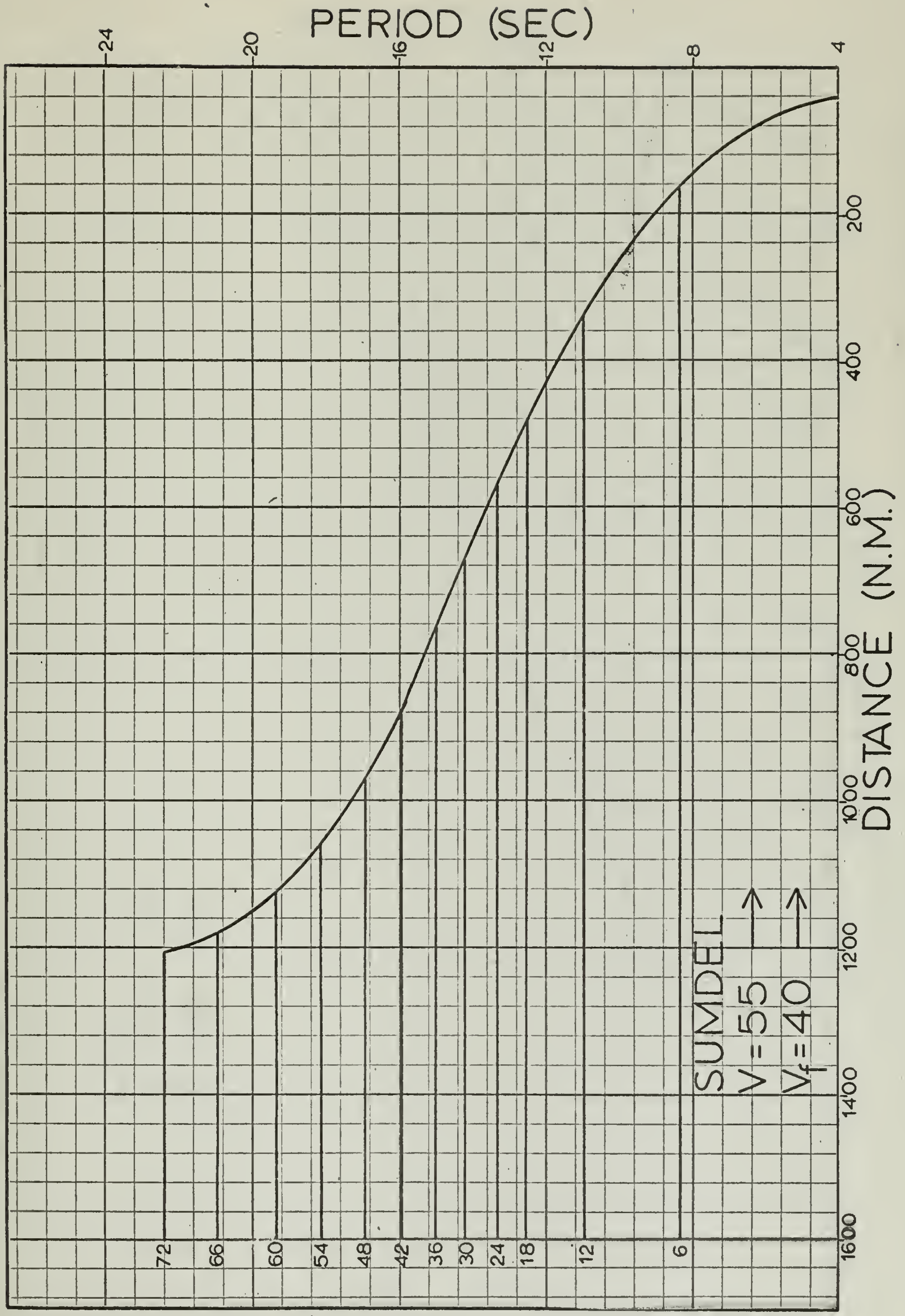


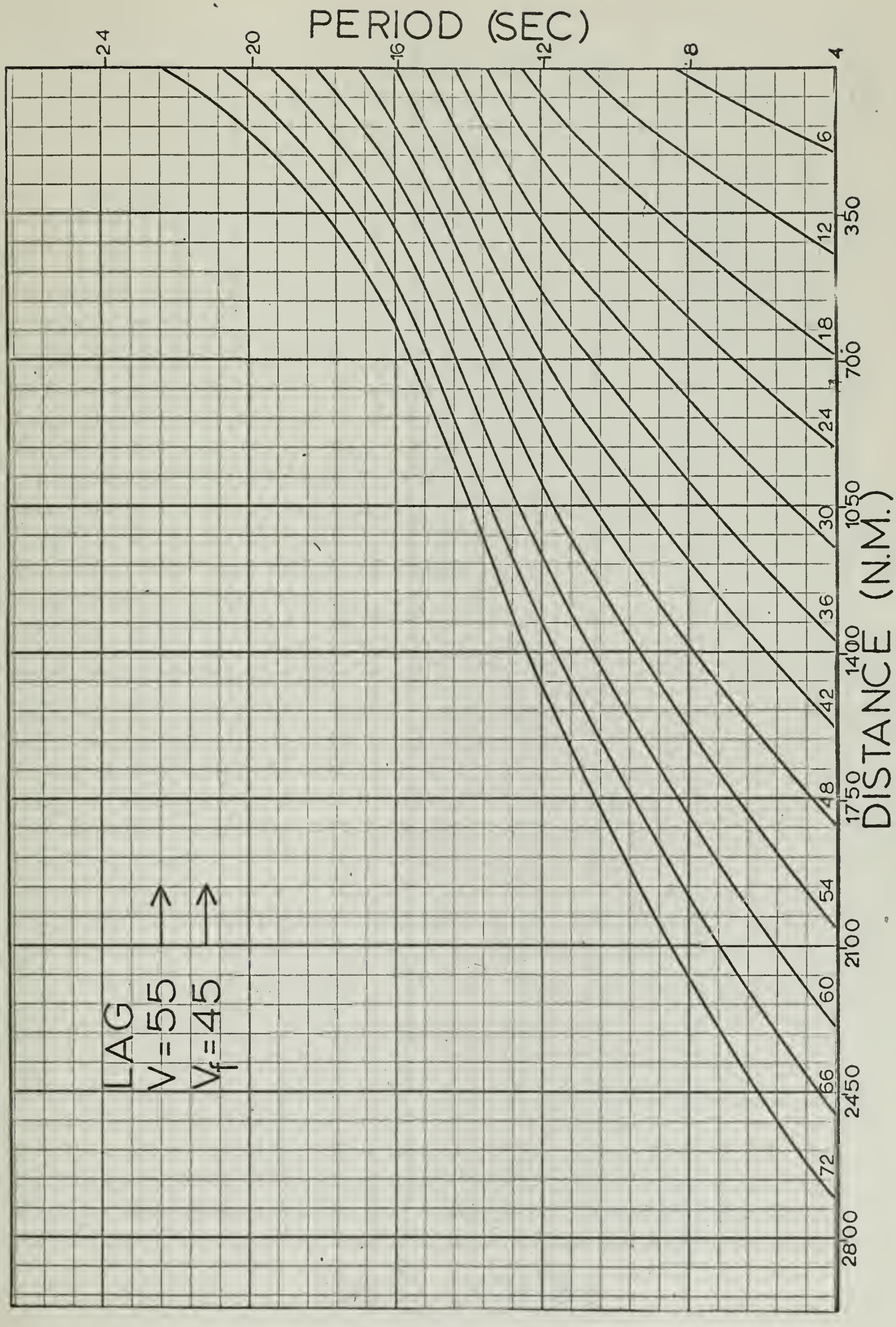
FOPRIME
V = 55
V_f = 35
DISTANCE (N.M.)
PERIOD (SEC)
200
400
600
800
1000
1200
1400
1600
4
8
12
16
20
24
6
12
18
24
30
36
42
48
54
60
66
72


PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
125
250
375
500
625
750
875
1000
72
66
60
54
48
42
36
30
24
18
12
6
SUMDEL
V = 55
V_f = 35

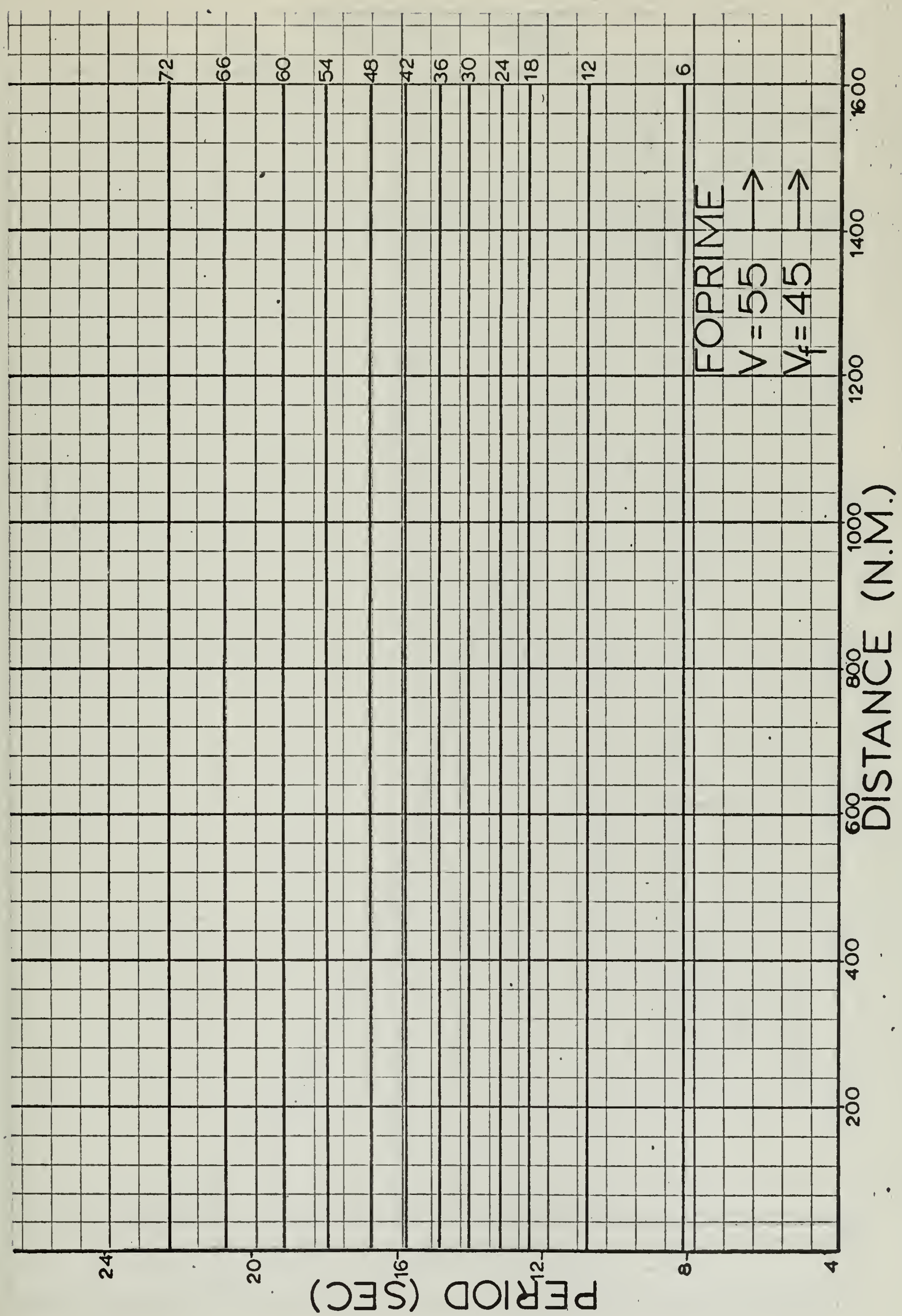

PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M)
300
600
900
1200
1500
1800
2100
2400
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V=55
$V_f$=40

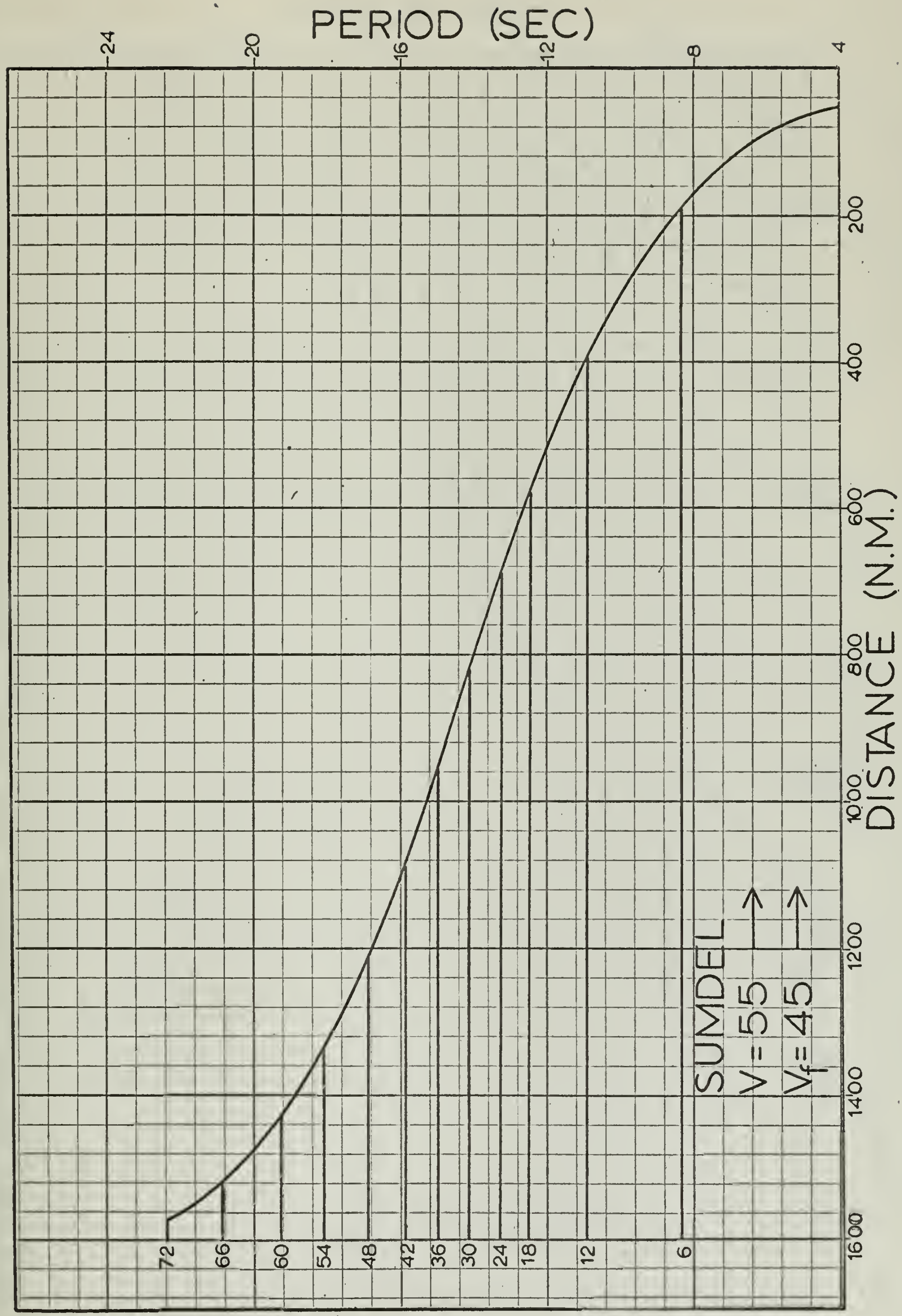

FOPRIME
V = 55
Vf = 40
DISTANCE (N.M.)
PERIOD (SEC)
200
400
600
800
1000
1200
1400
1600
4
8
12
16
20
24
6
12
18
24
30
36
42
48
54
60
66
72

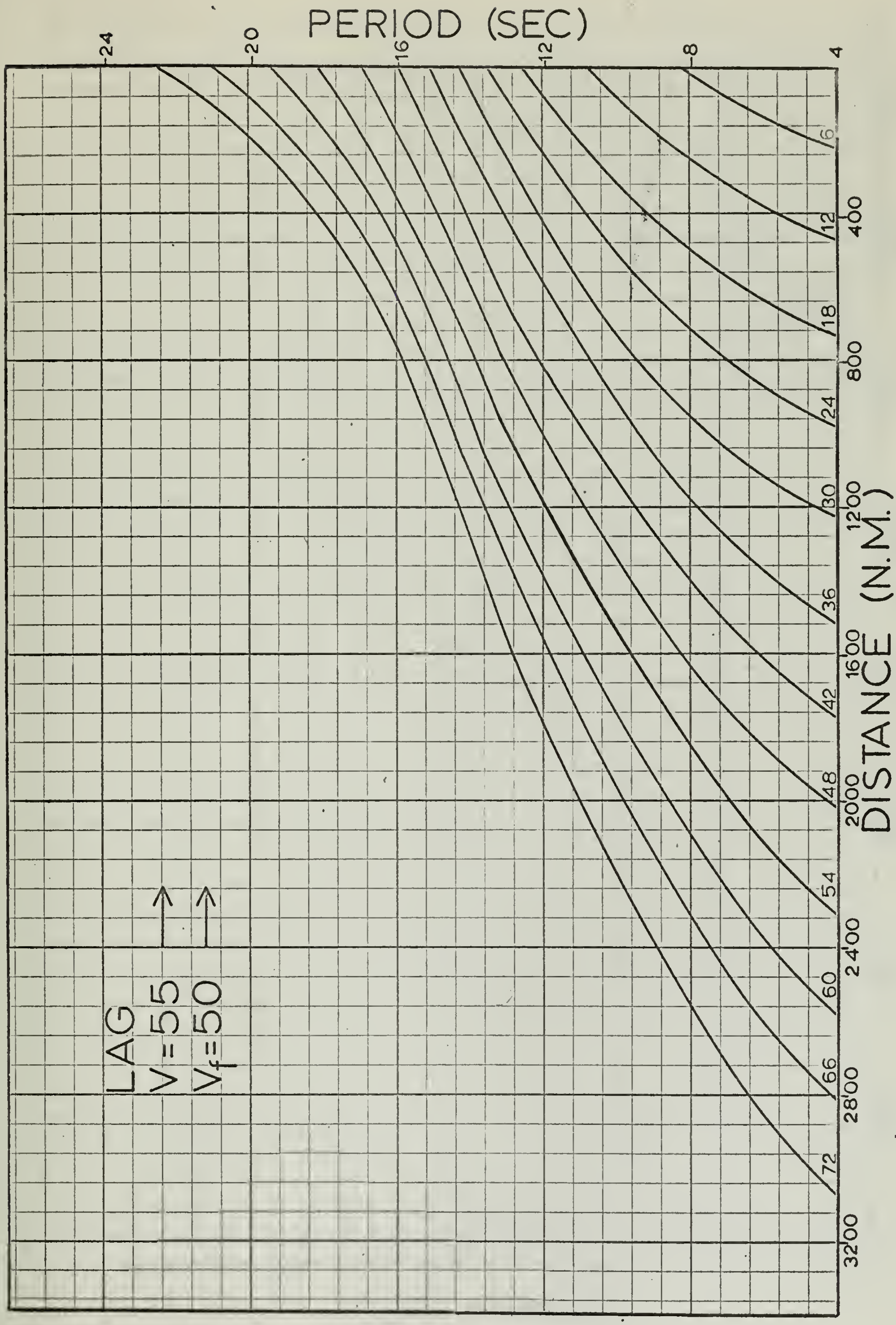

PERIOD (SEC)
24
20
16
12
8
4
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
SUMDEL
V = 55
V_f = 40
72
66
60
54
48
42
36
30
24
18
12
6

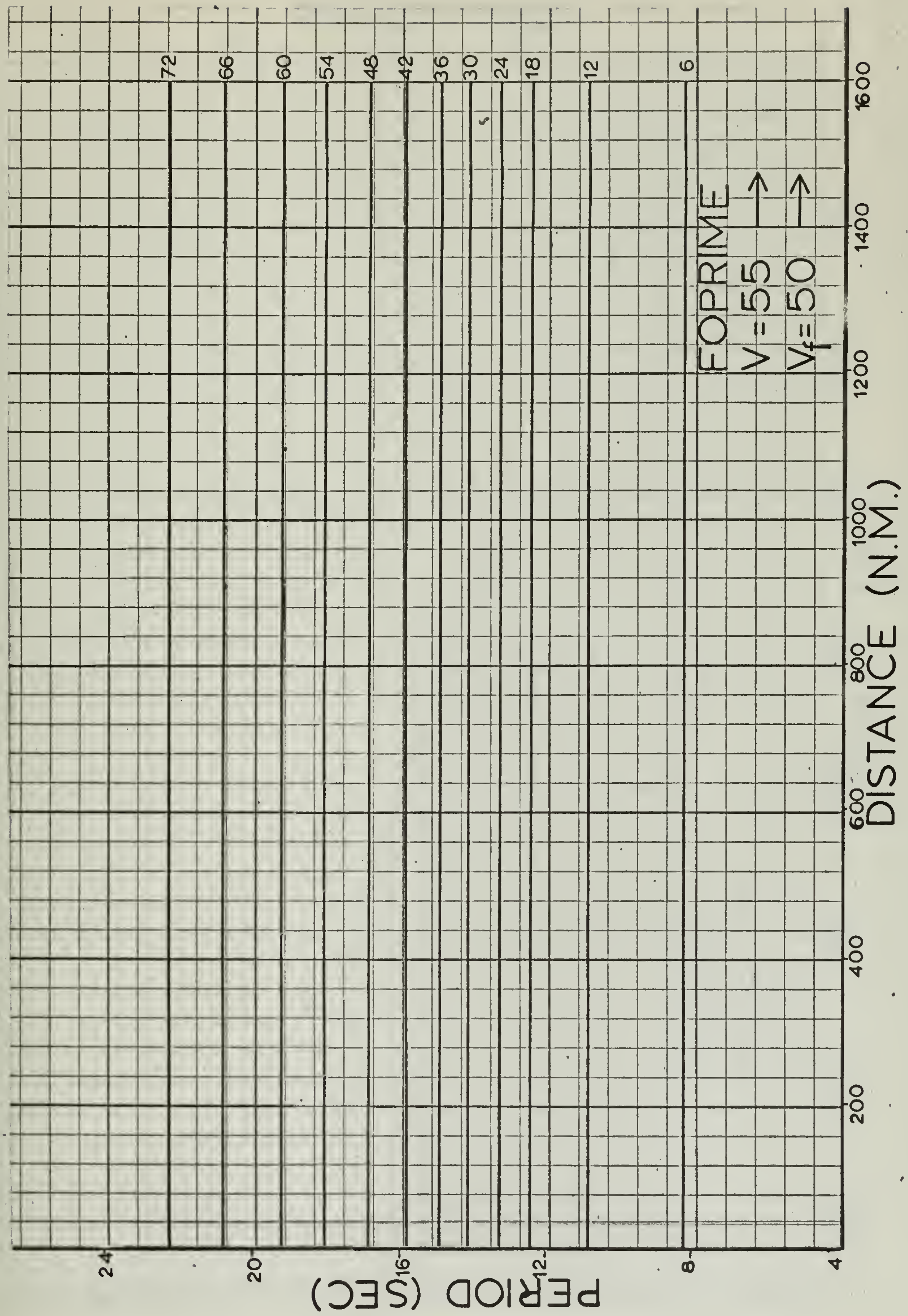


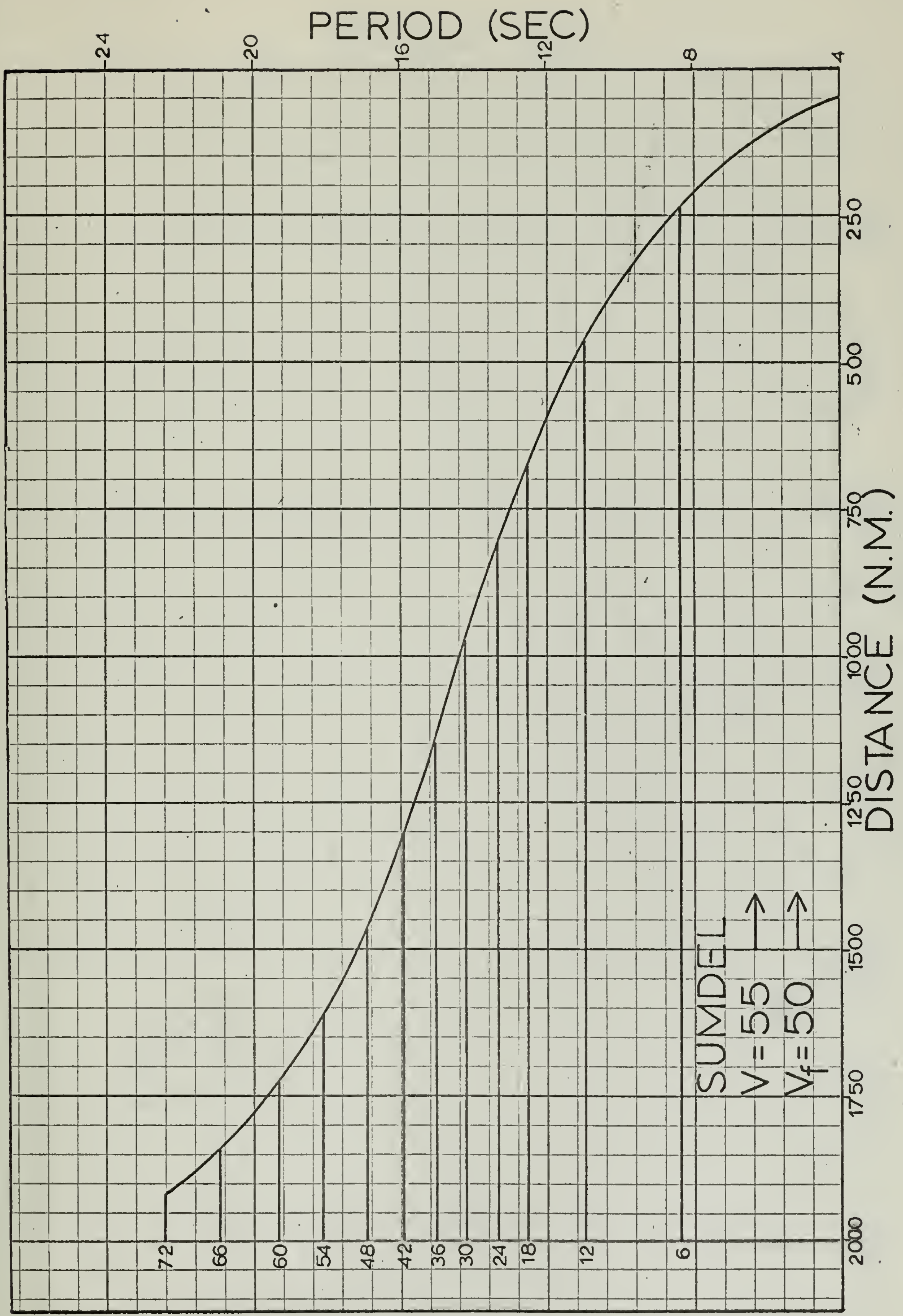
PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
350
700
1050
1400
1750
2100
2450
2800
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 55 →
V_f = 45 →

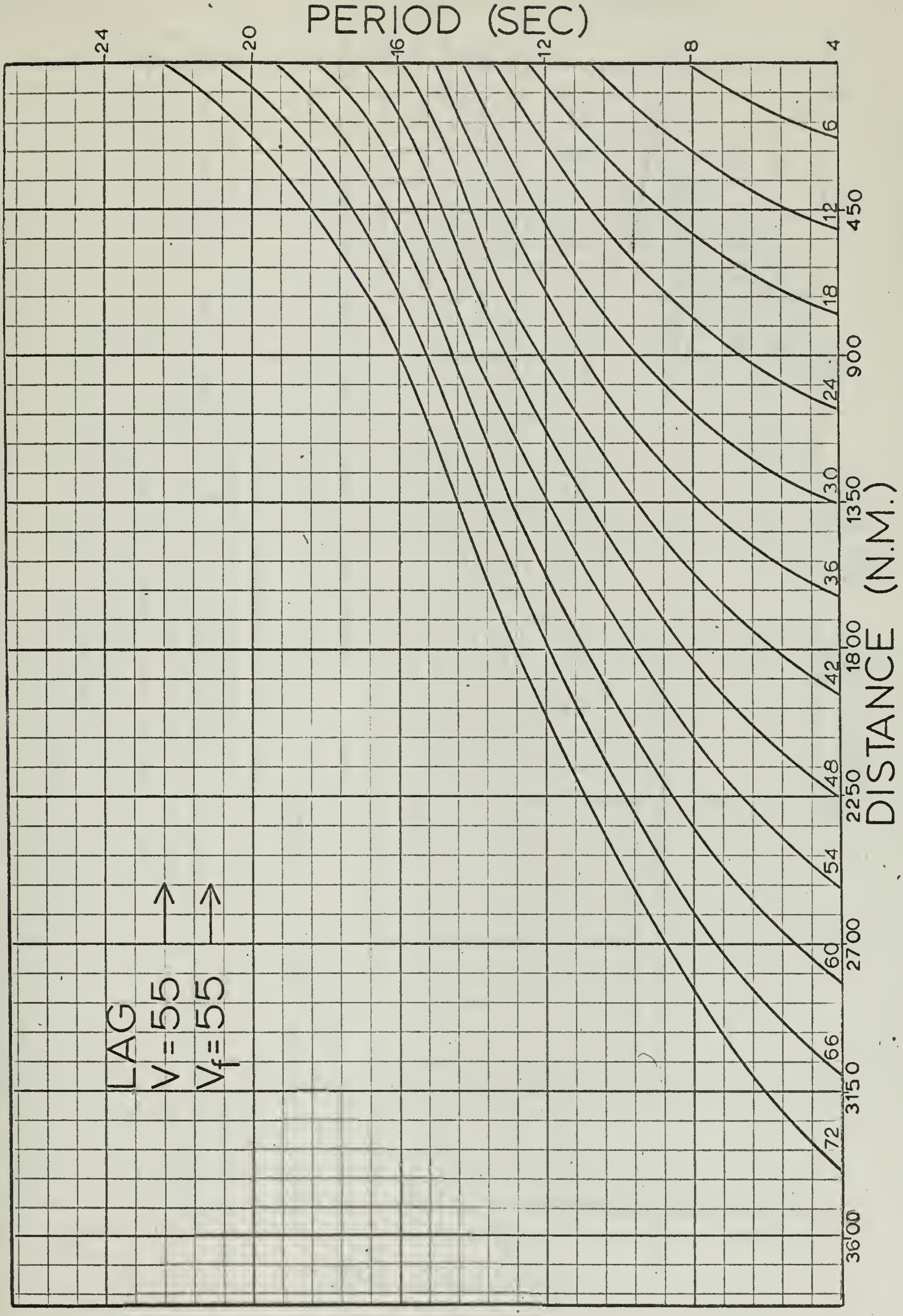

FOPRIME
V = 55
Vf = 45
DISTANCE (N.M.)
PERIOD (SEC)
200
400
600
800
1000
1200
1400
1600
4
8
12
16
20
24
6
12
18
24
30
36
42
48
54
60
66
72

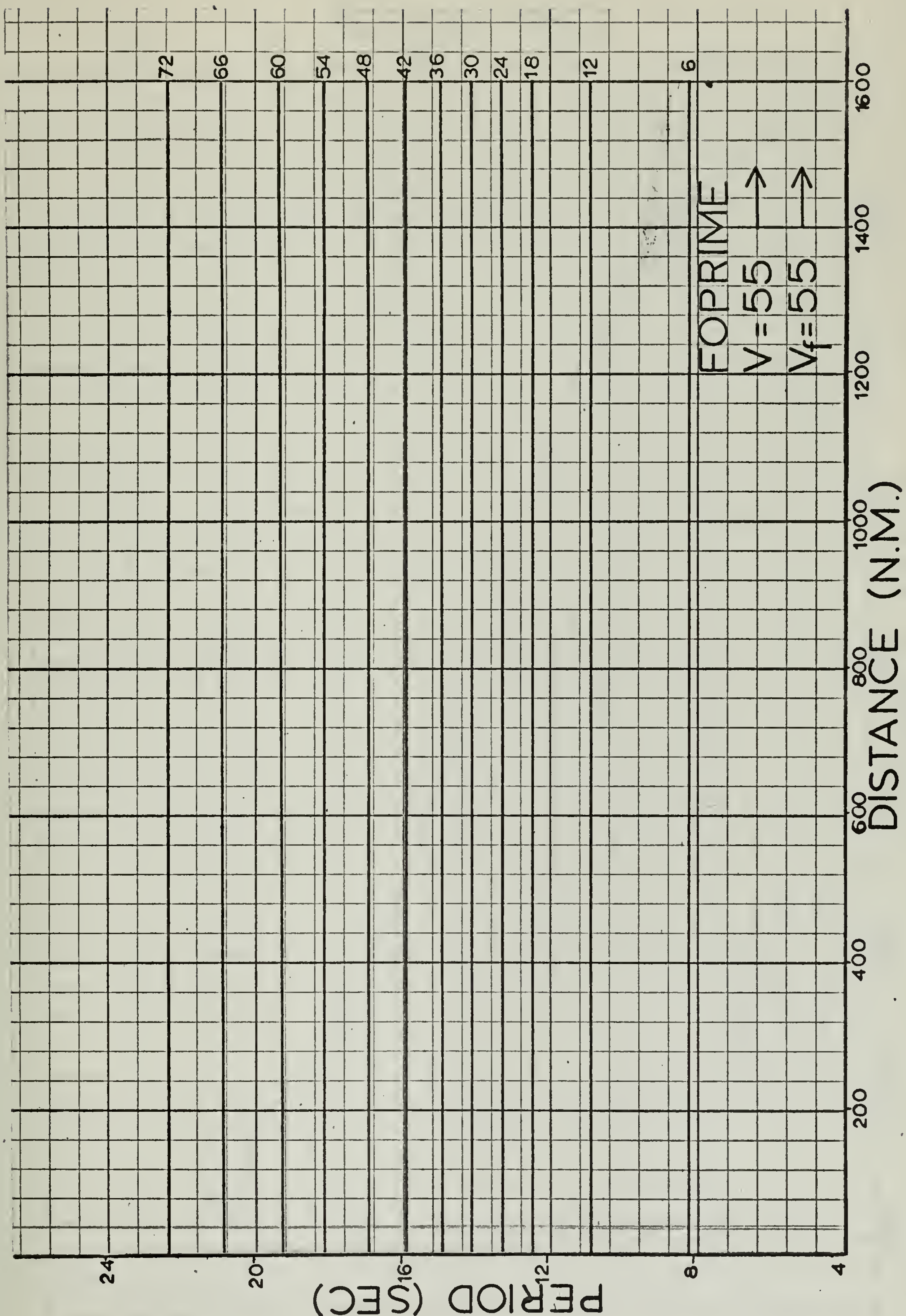

PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
SUMDEL
V = 55
Vf = 45
72
66
60
54
48
42
36
30
24
18
12
6


PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
400
800
1200
1600
2000
2400
2800
3200
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 55
Vf = 50

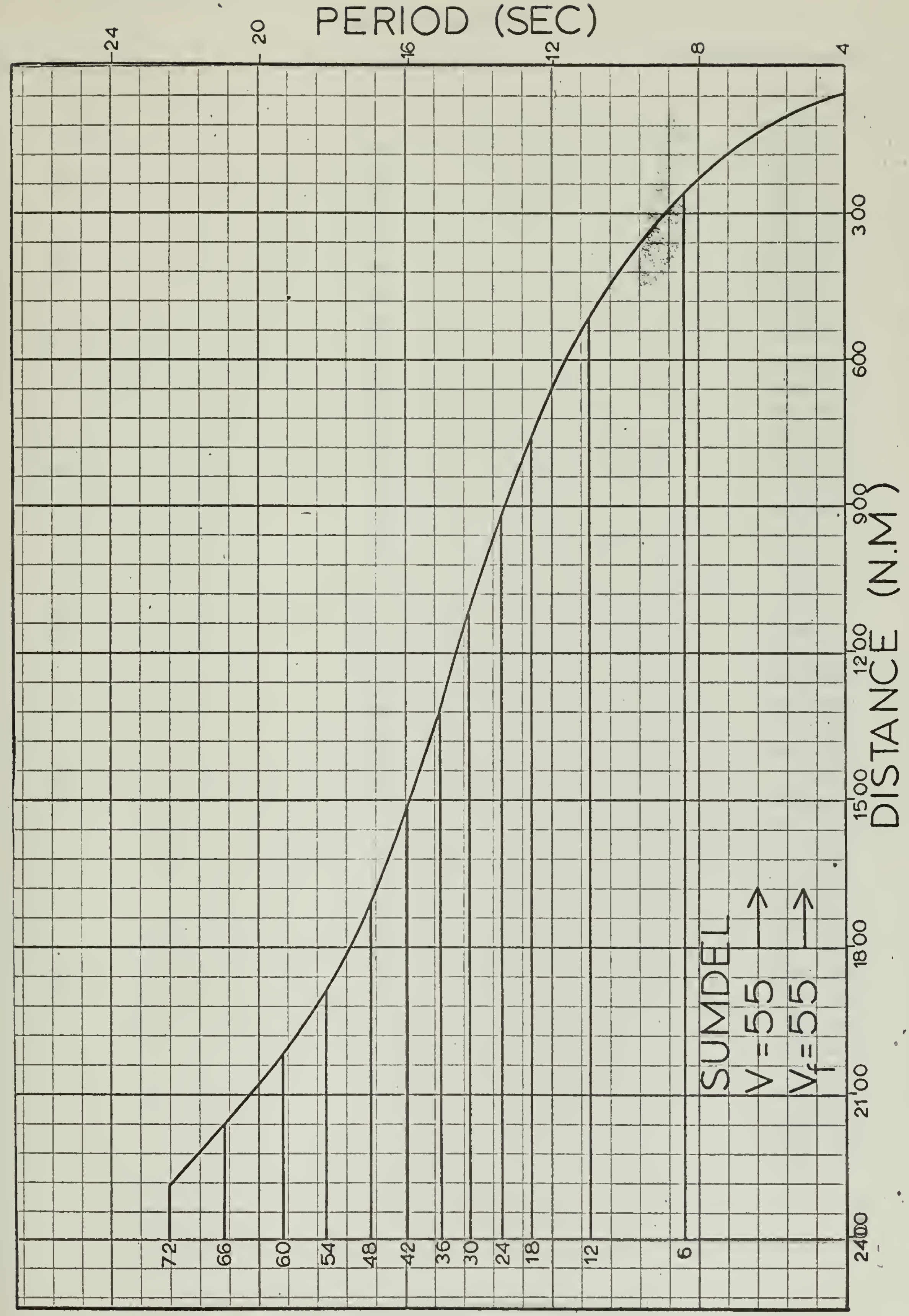

FOPRIME
V = 55
$V_f$ = 50
DISTANCE (N.M.)
PERIOD (SEC)
200
400
600
800
1000
1200
1400
1600
4
8
12
16
20
24
6
12
18
24
30
36
42
48
54
60
66
72


PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
250
500
750
1000
1250
1500
1750
2000
72
66
60
54
48
42
36
30
24
18
12
6
SUMDEL
V = 55
Vf = 50


PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
450
900
1350
1800
2250
2700
3150
3600
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V = 55
$V_f$ = 55

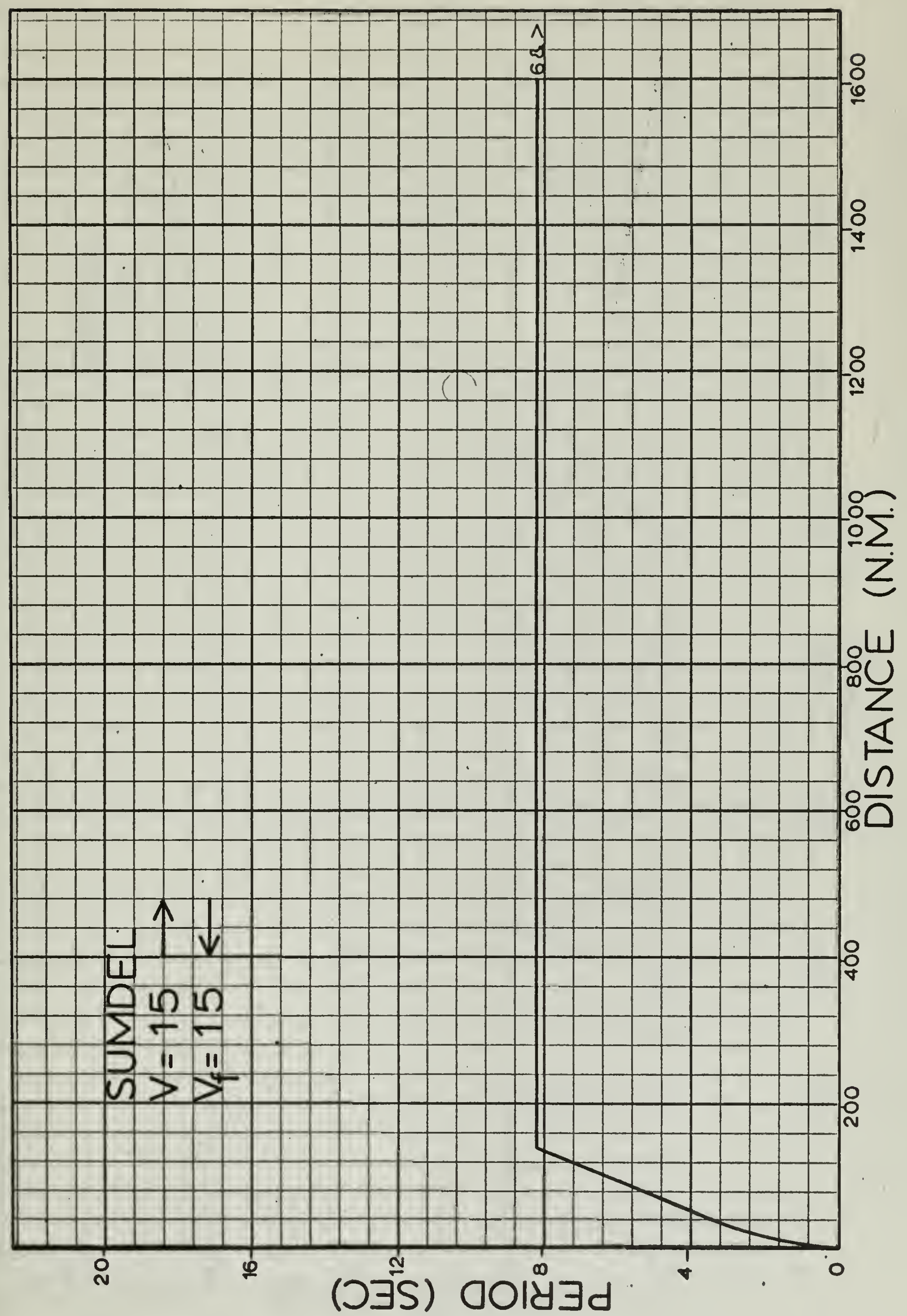


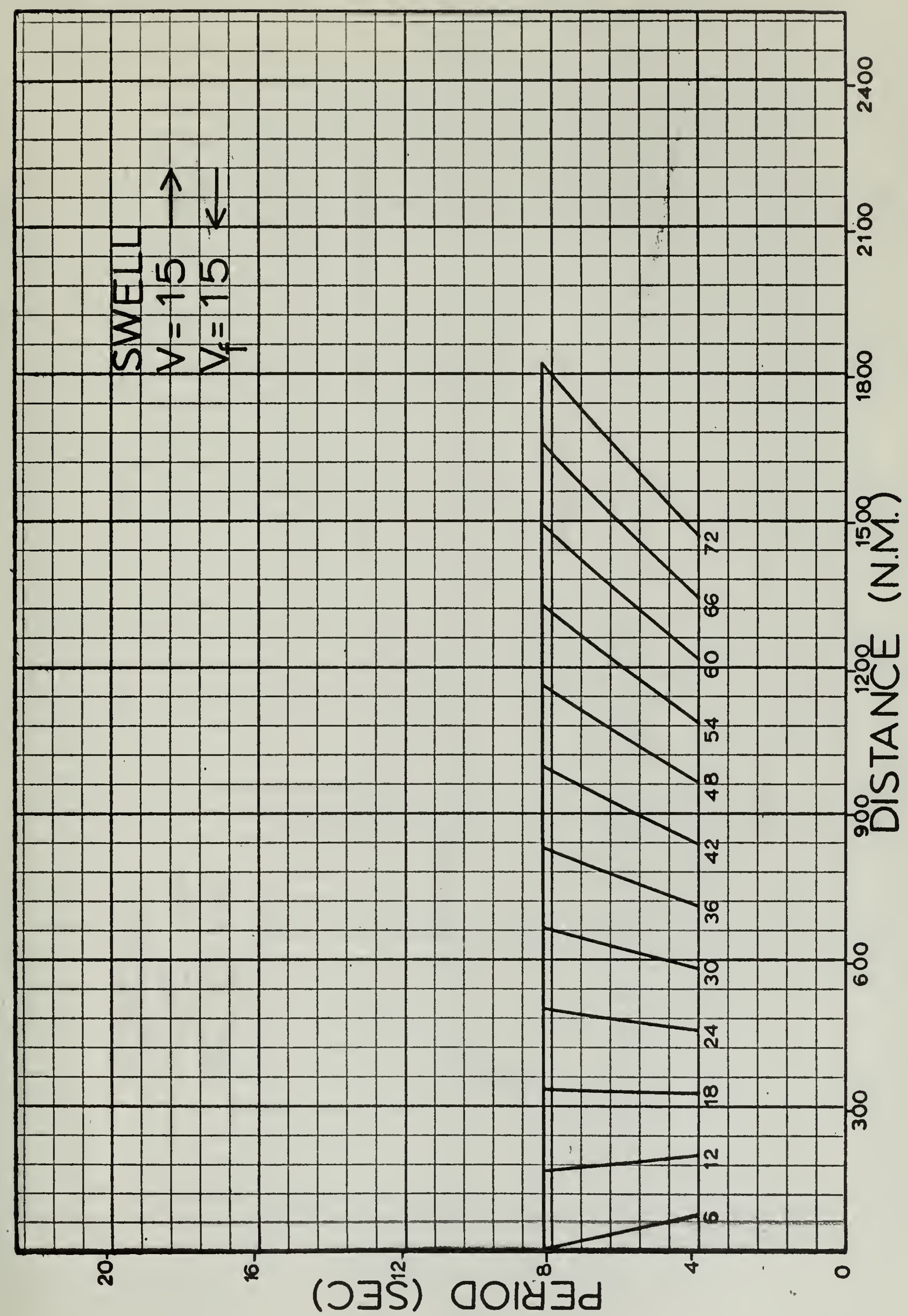
FOPRIME
V = 55 →
Vf = 55 →
72
66
60
54
48
42
36
30
24
18
12
6
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
PERIOD (SEC)
4
8
12
16
20
24


PERIOD (SEC)
24
20
16
12
8
4
DISTANCE (N.M.)
300
600
900
1200
1500
1800
2100
2400
SUMDEL
V = 55
$V_f$ = 55
72
66
60
54
48
42
36
30
24
18
12
6

18.3 Moving (windward) Fetch Model Graphs

INDEX OF GRAPHS


SUMDEL
V = 15
Vf = 15
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600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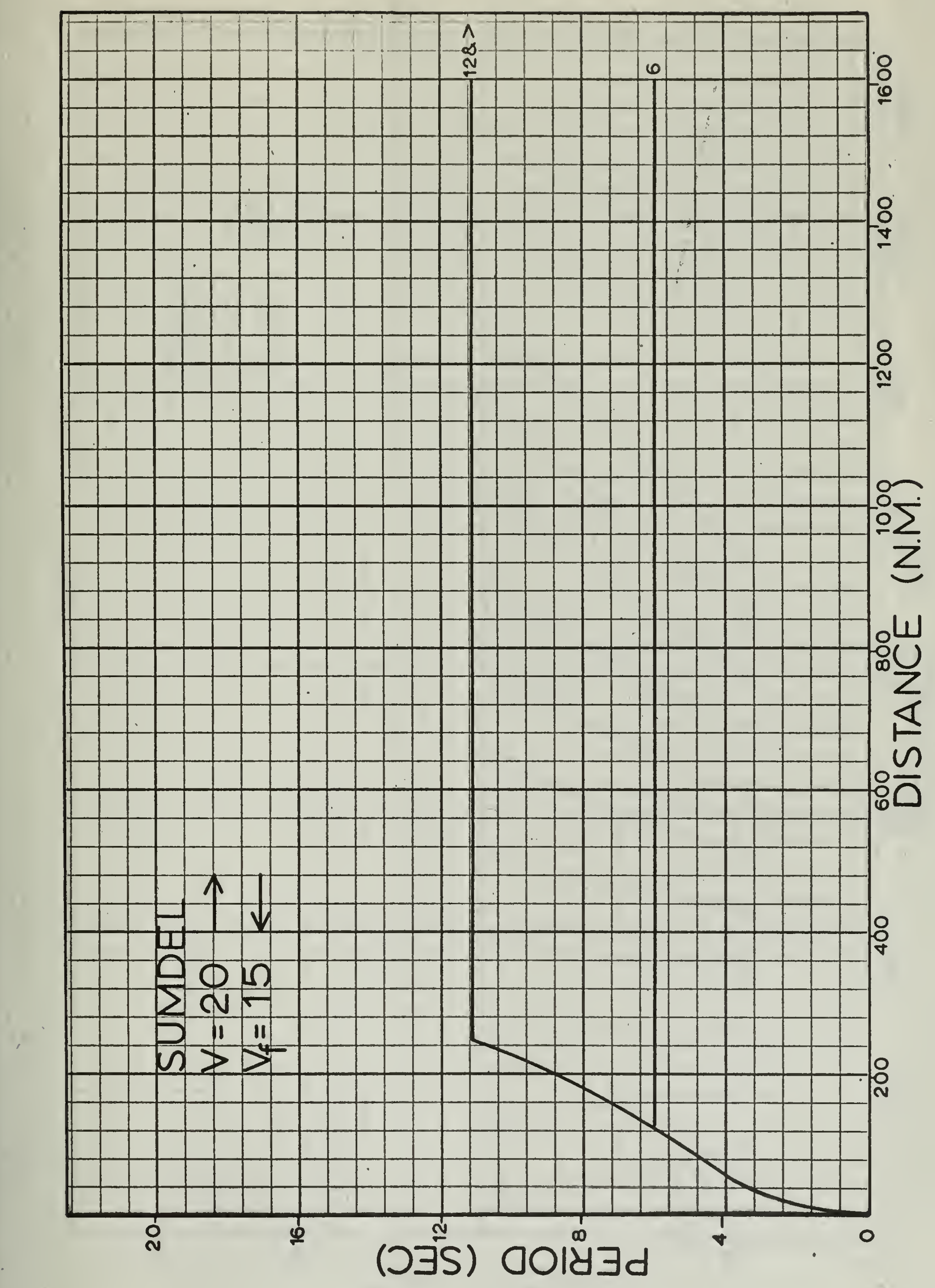
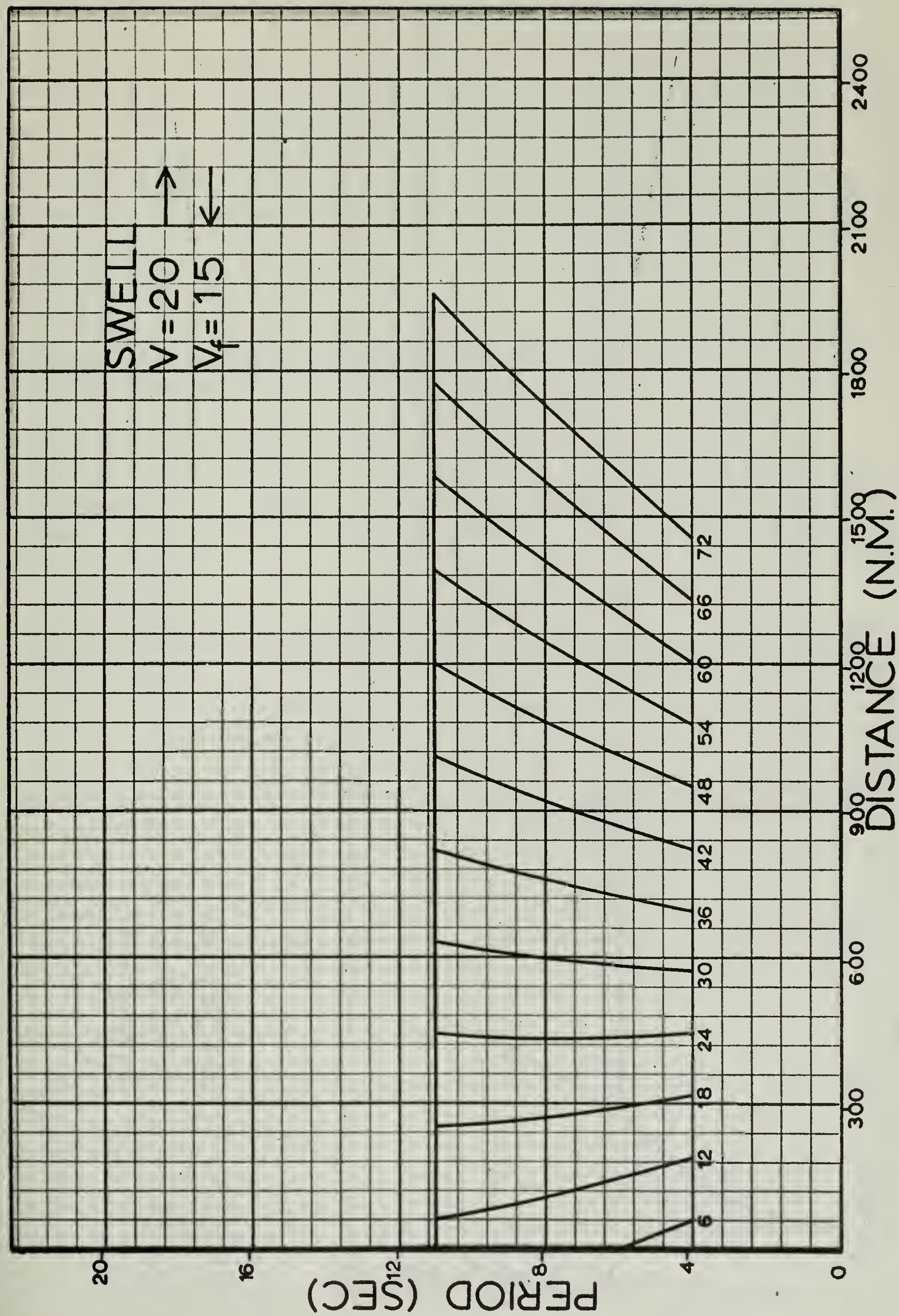
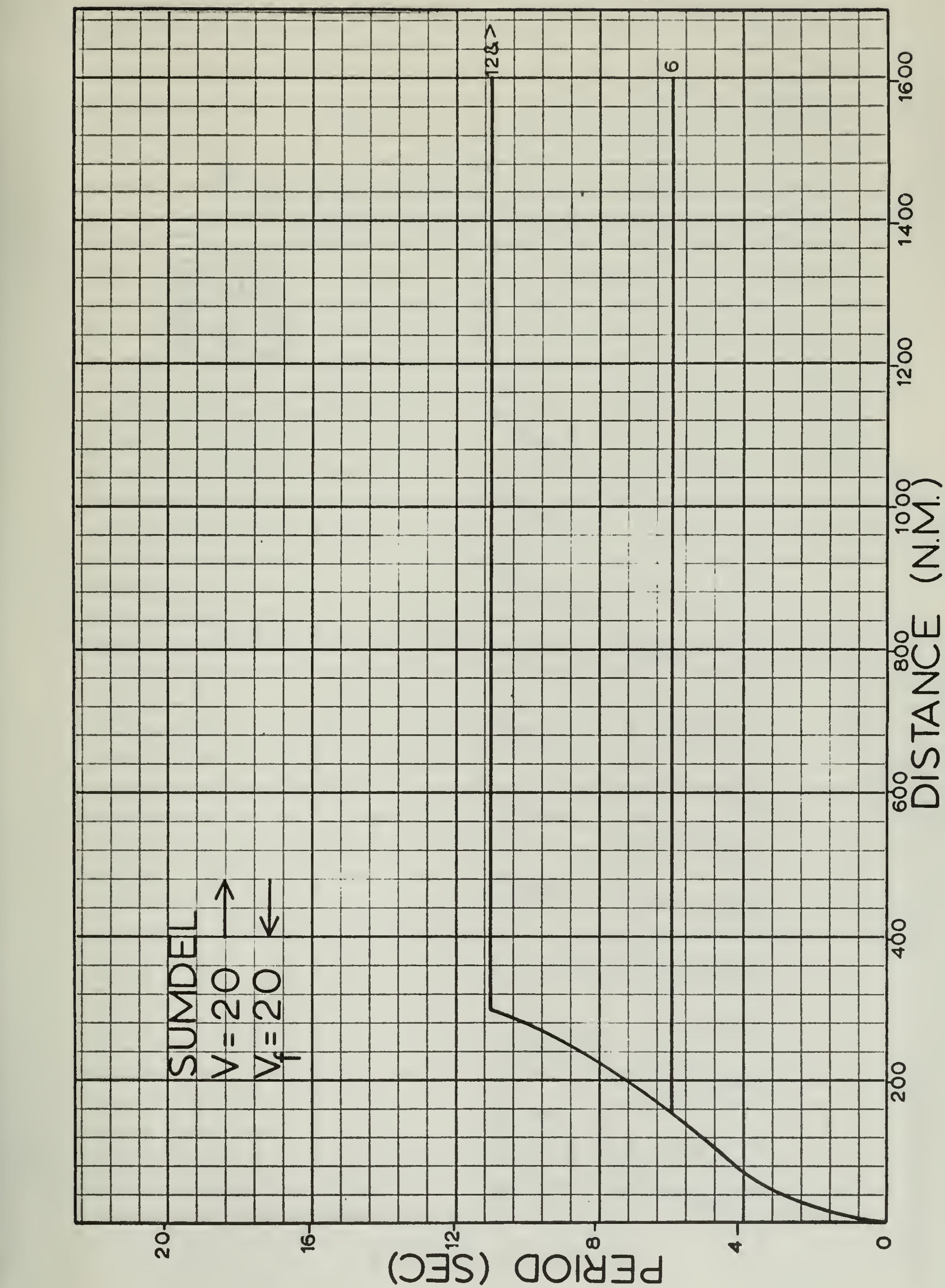
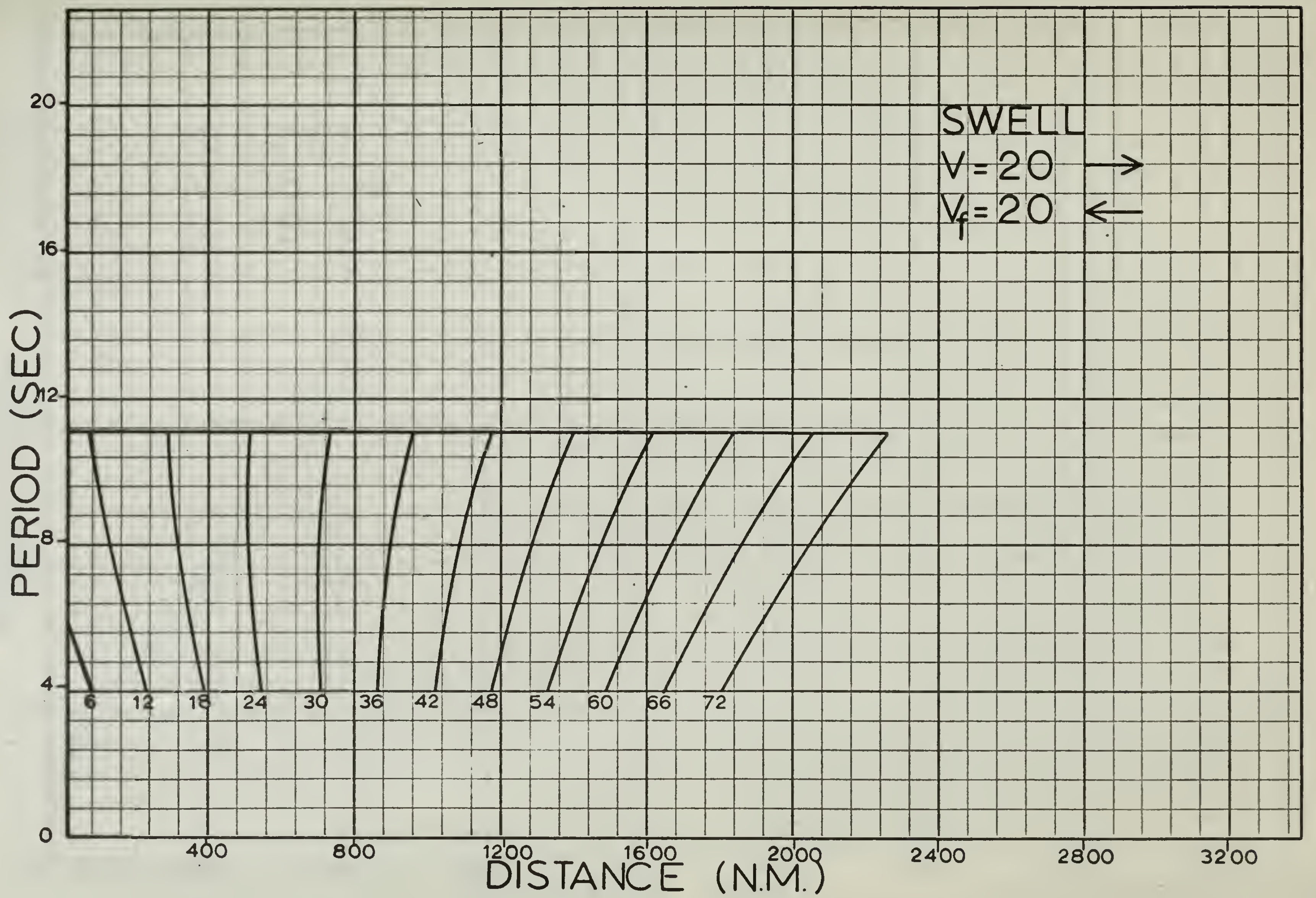
$V_f$ = 15
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
300
600
900
1200
1500
1800
2100
2400
6
12
18
24
30
36
42
48
54
60
66
72

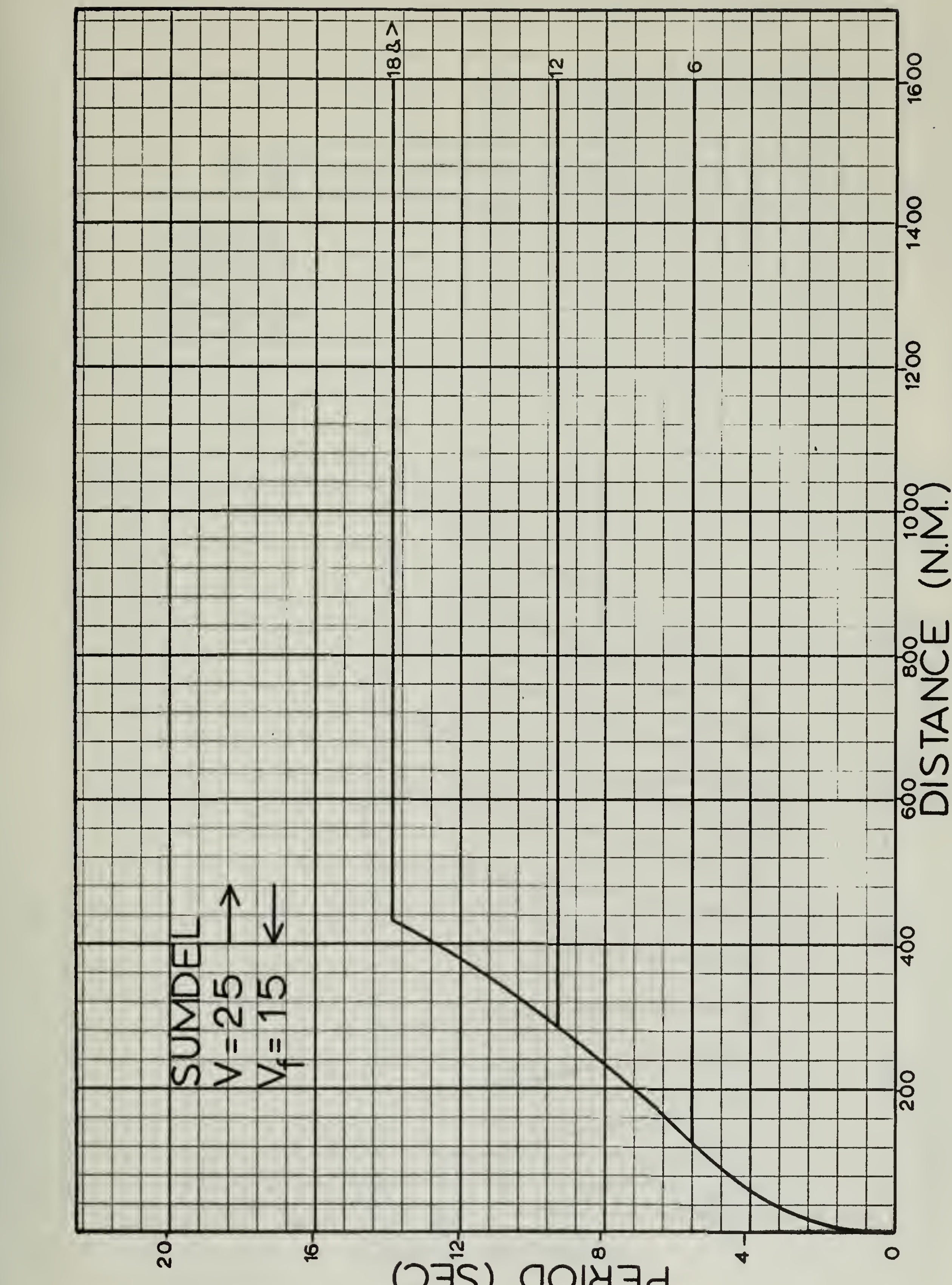

SUMDEL
V = 20
V_f = 15
12&>
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600

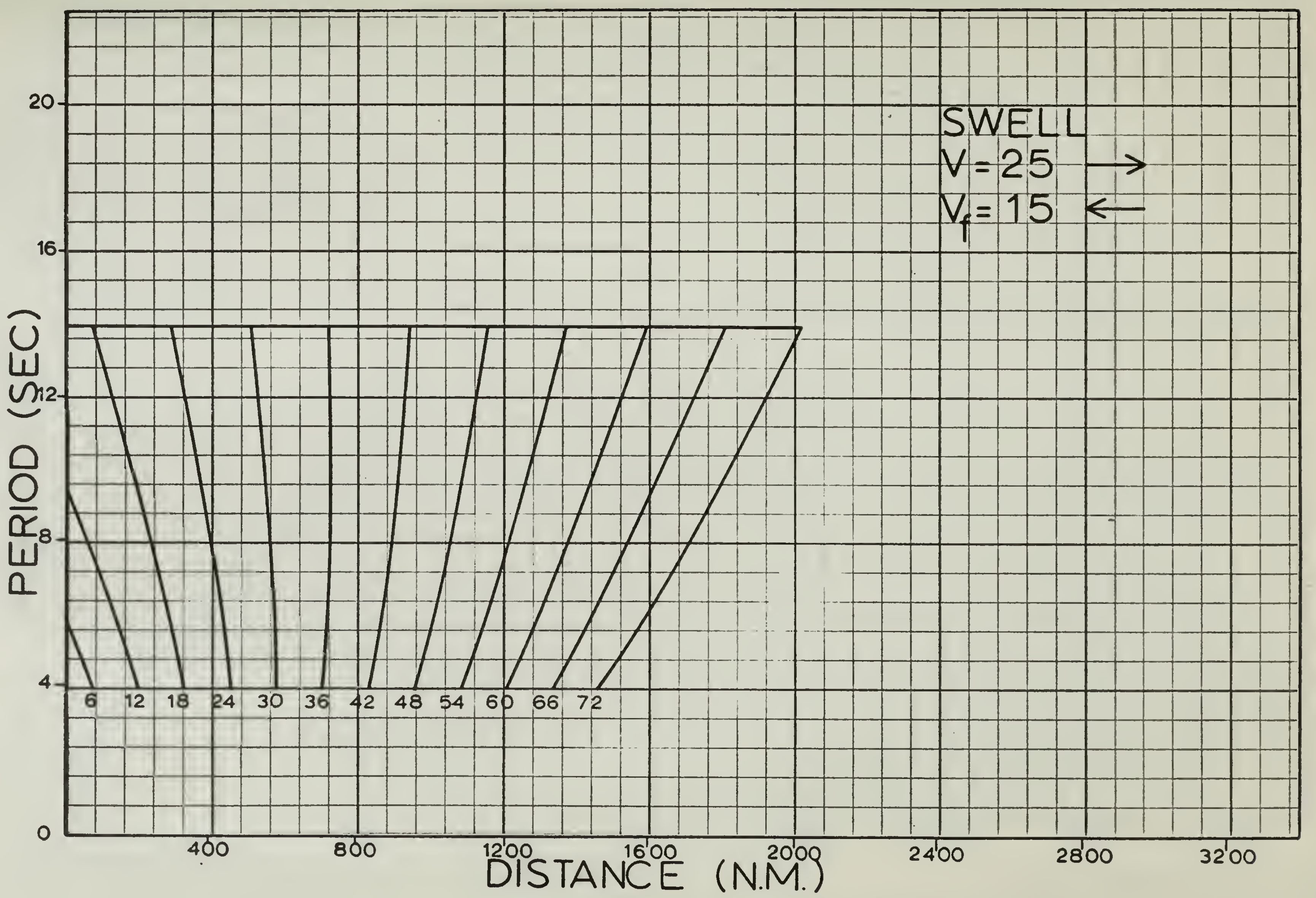


SWELL
V = 20
$V_f$ = 15
6
12
18
24
30
36
42
48
54
60
66
72
0
4
8
12
16
20
PERIOD (SEC)
300
600
900
1200
1500
1800
2100
2400
DISTANCE (N.M.)

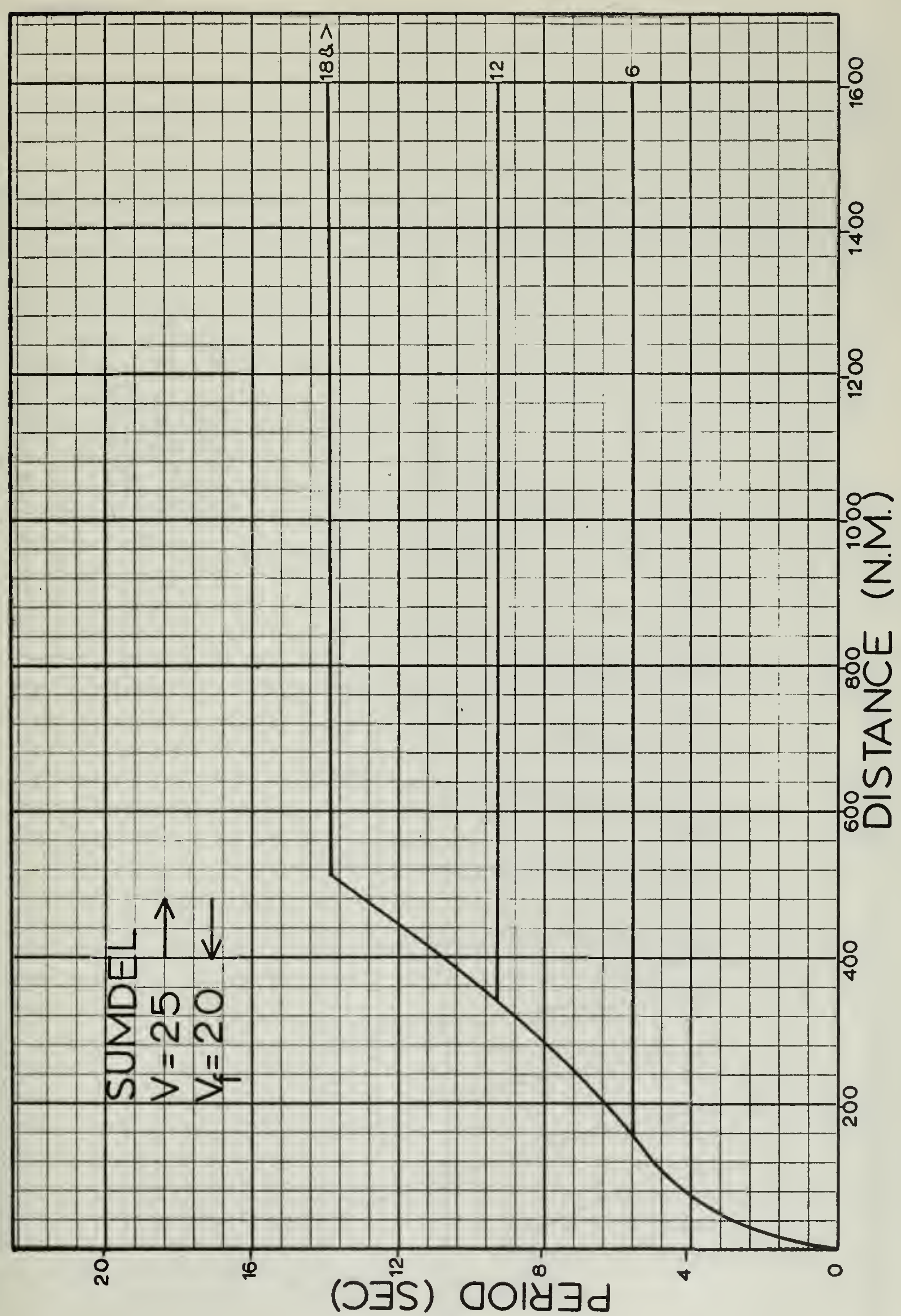

SUMDEL
V = 20
$V_f$ = 20
12 & >
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600

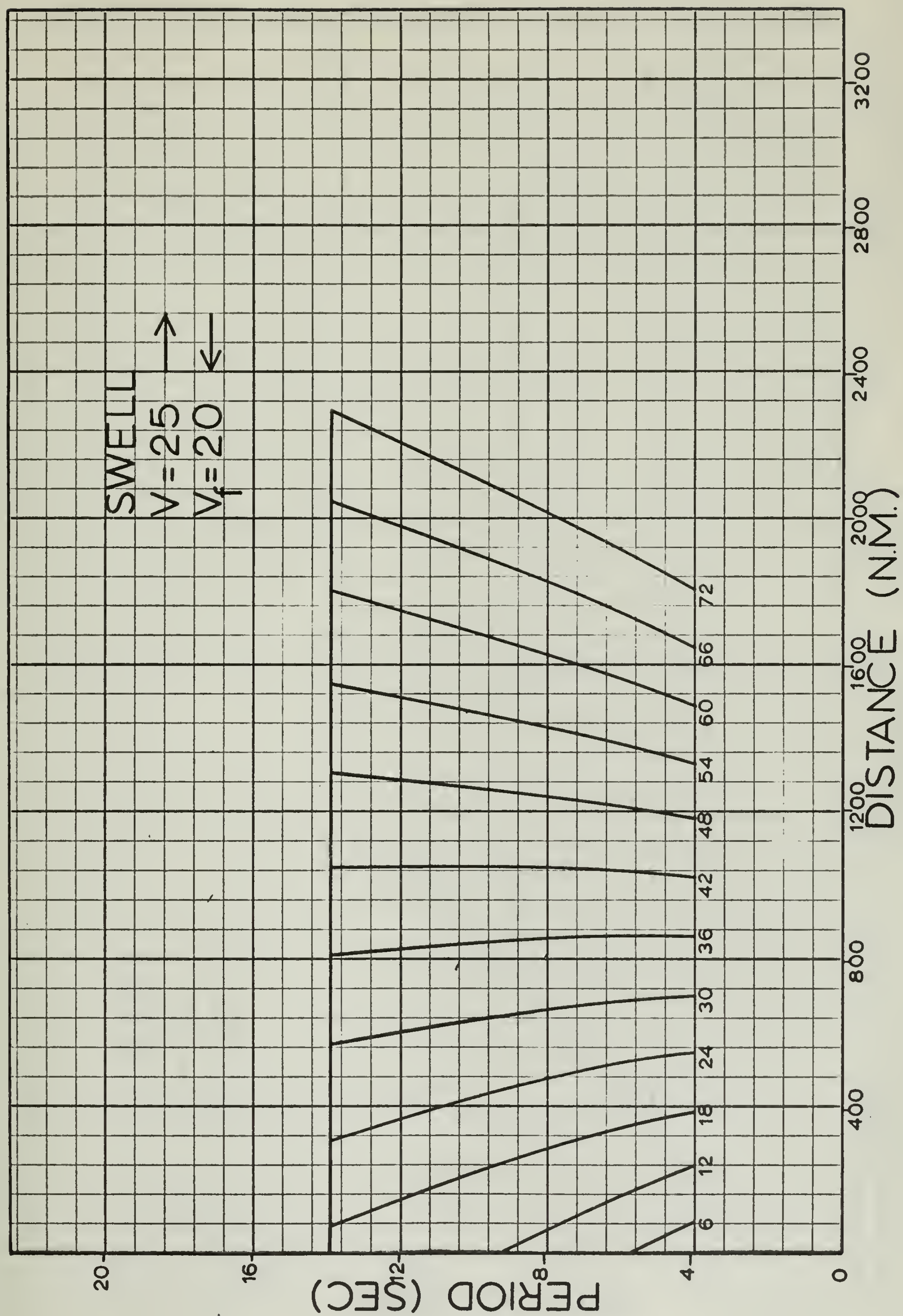

SWELL
V = 20
$V_f$ = 20
PERIOD (SEC)
20
16
12
8
4
0
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)


SUMDEL
V = 25
V_f = 15
18 & >
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600



SWELL
V = 25
$V_f$ = 15
20
16
12
8
4
0
PERIOD (SEC)
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)


SUMDEL
V = 25 →
Vf = 20 ←
18 & >
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600


SWELL
V = 25
$V_f$ = 20
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
400
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2400
2800
3200
6
12
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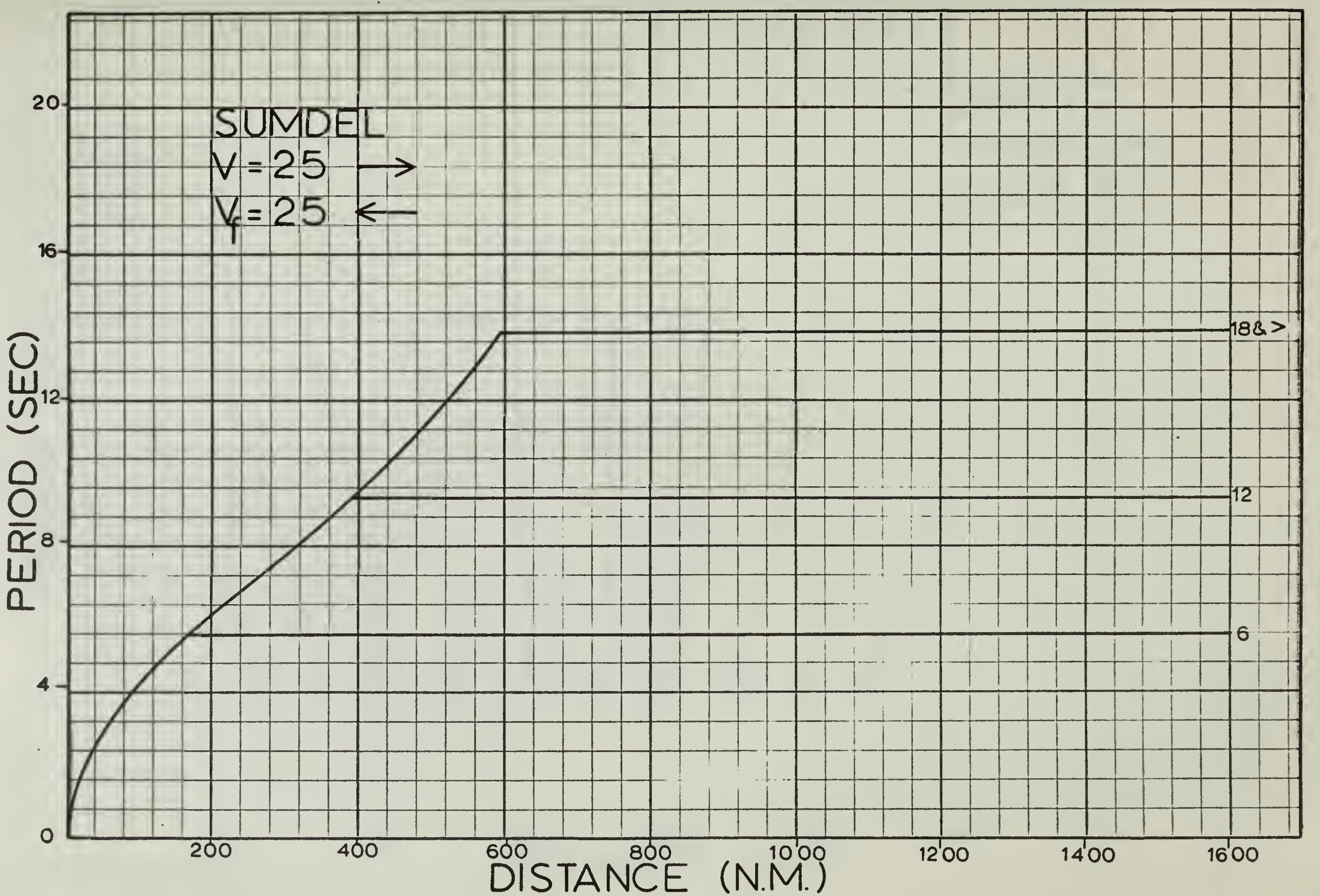
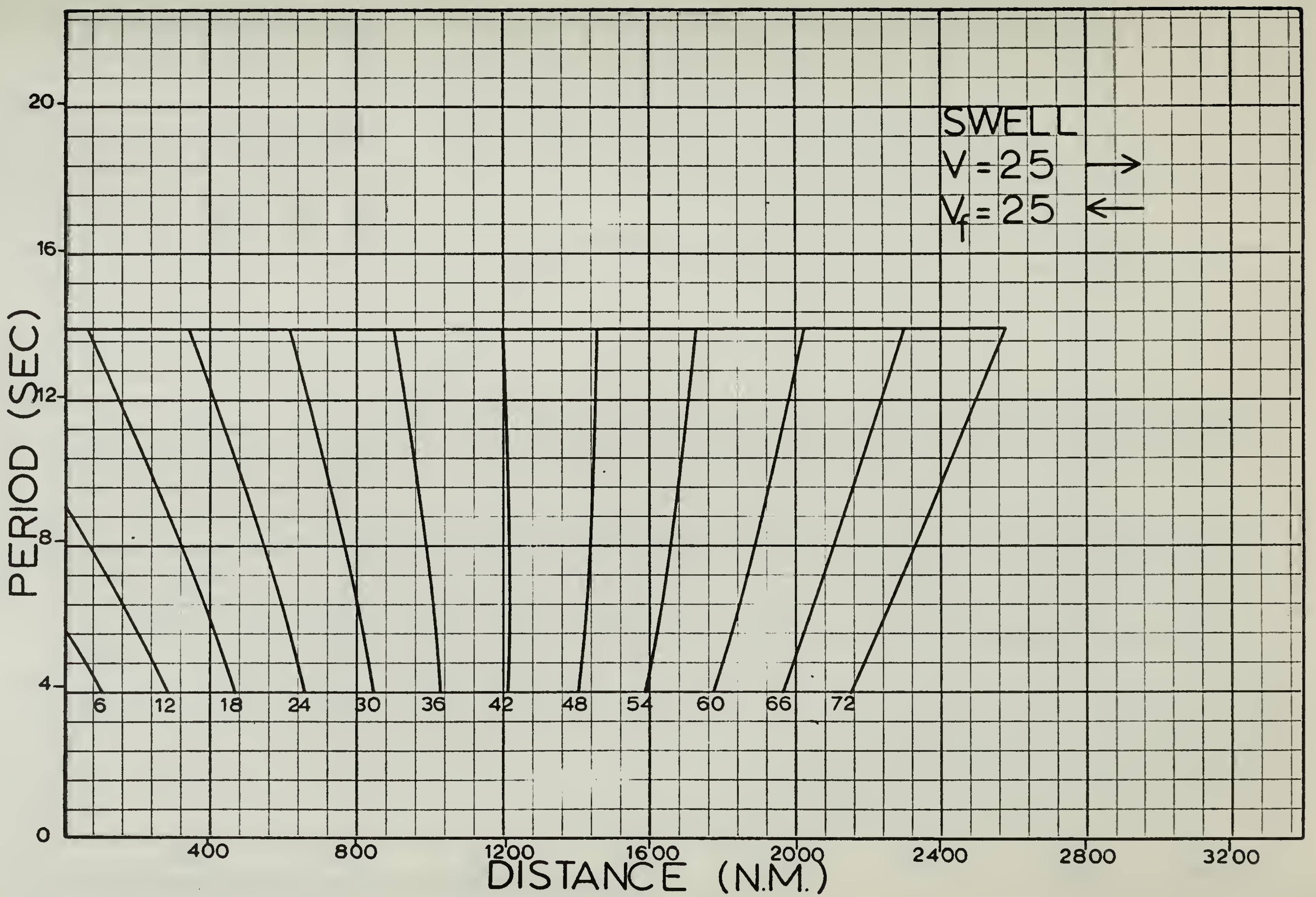
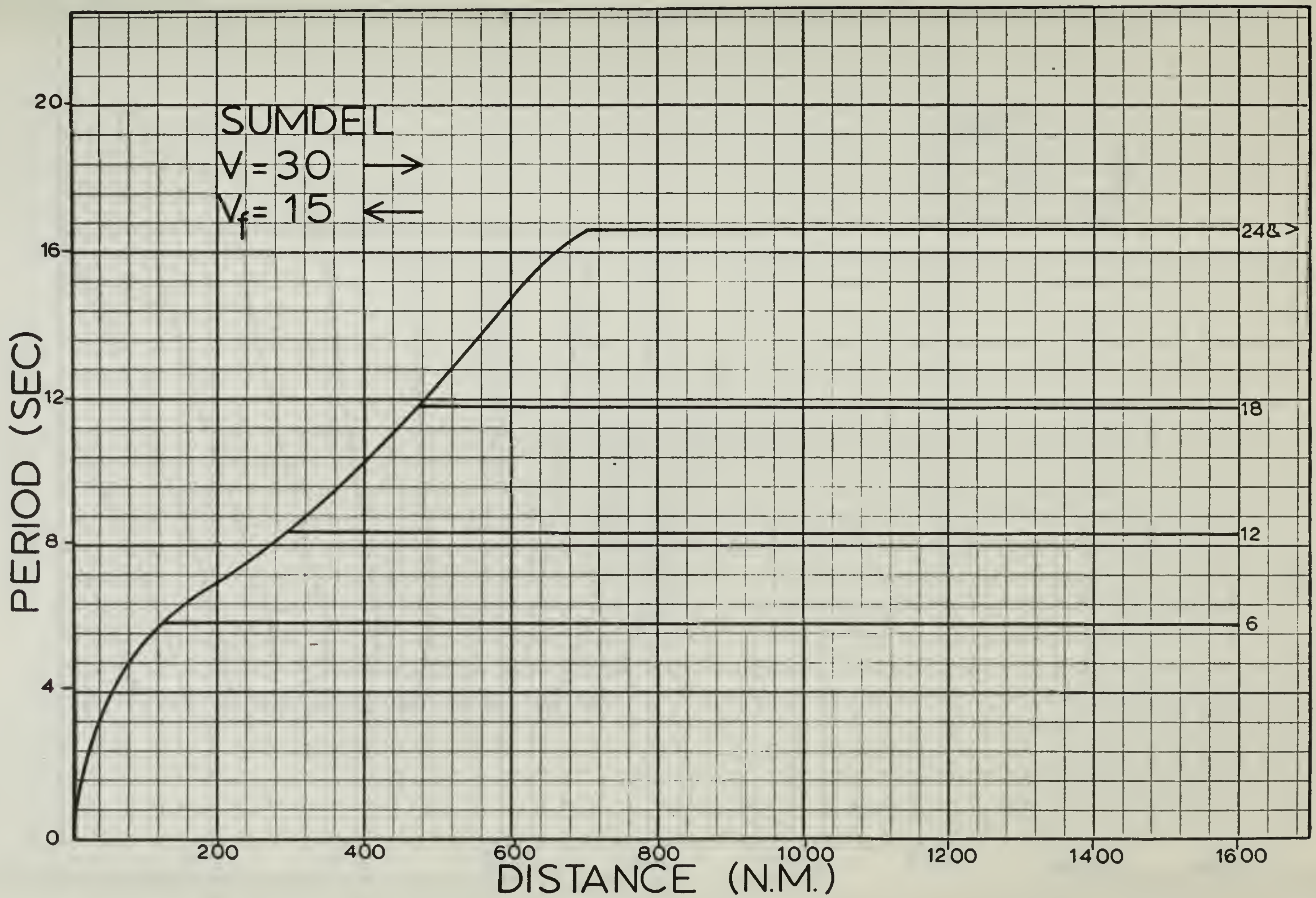
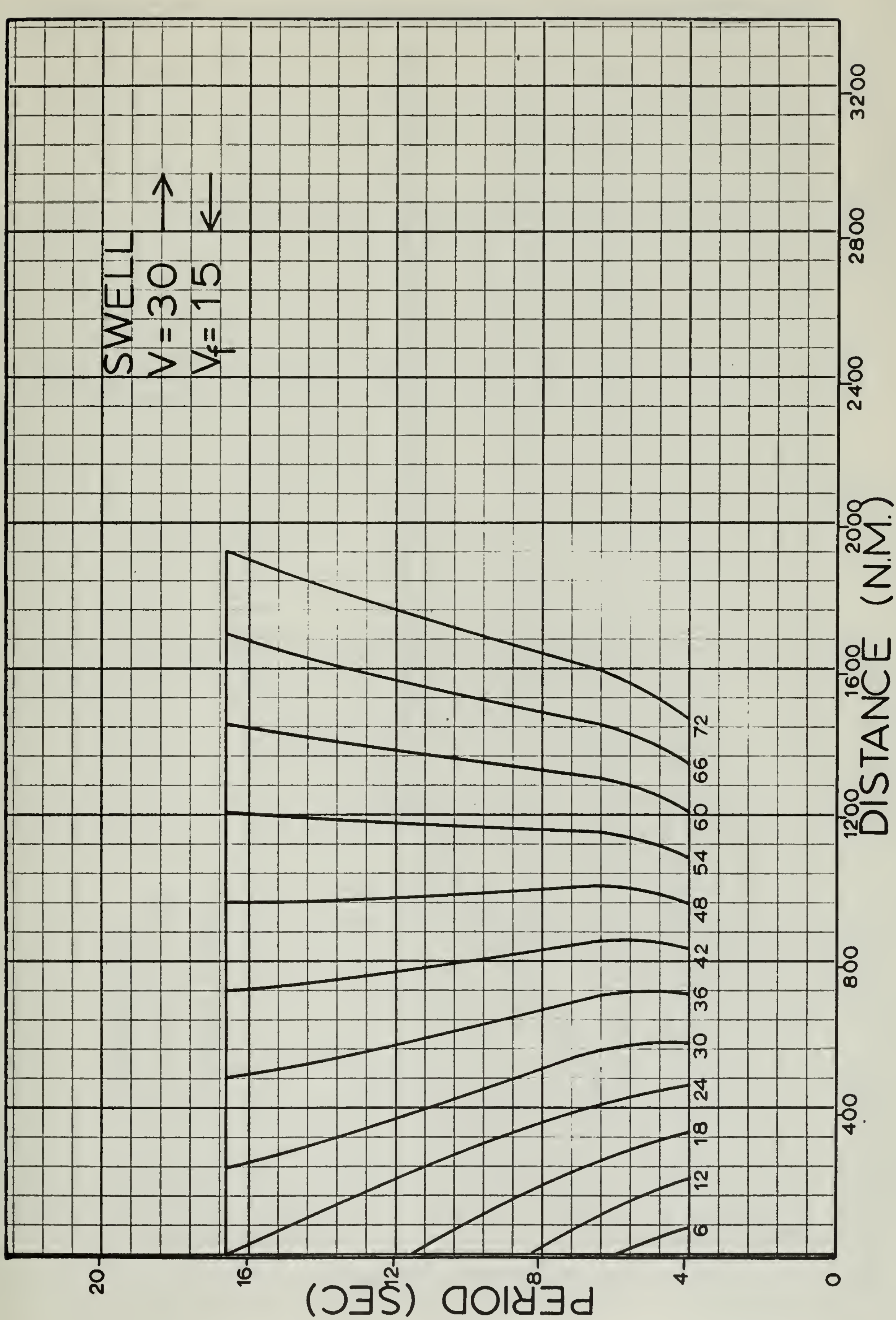
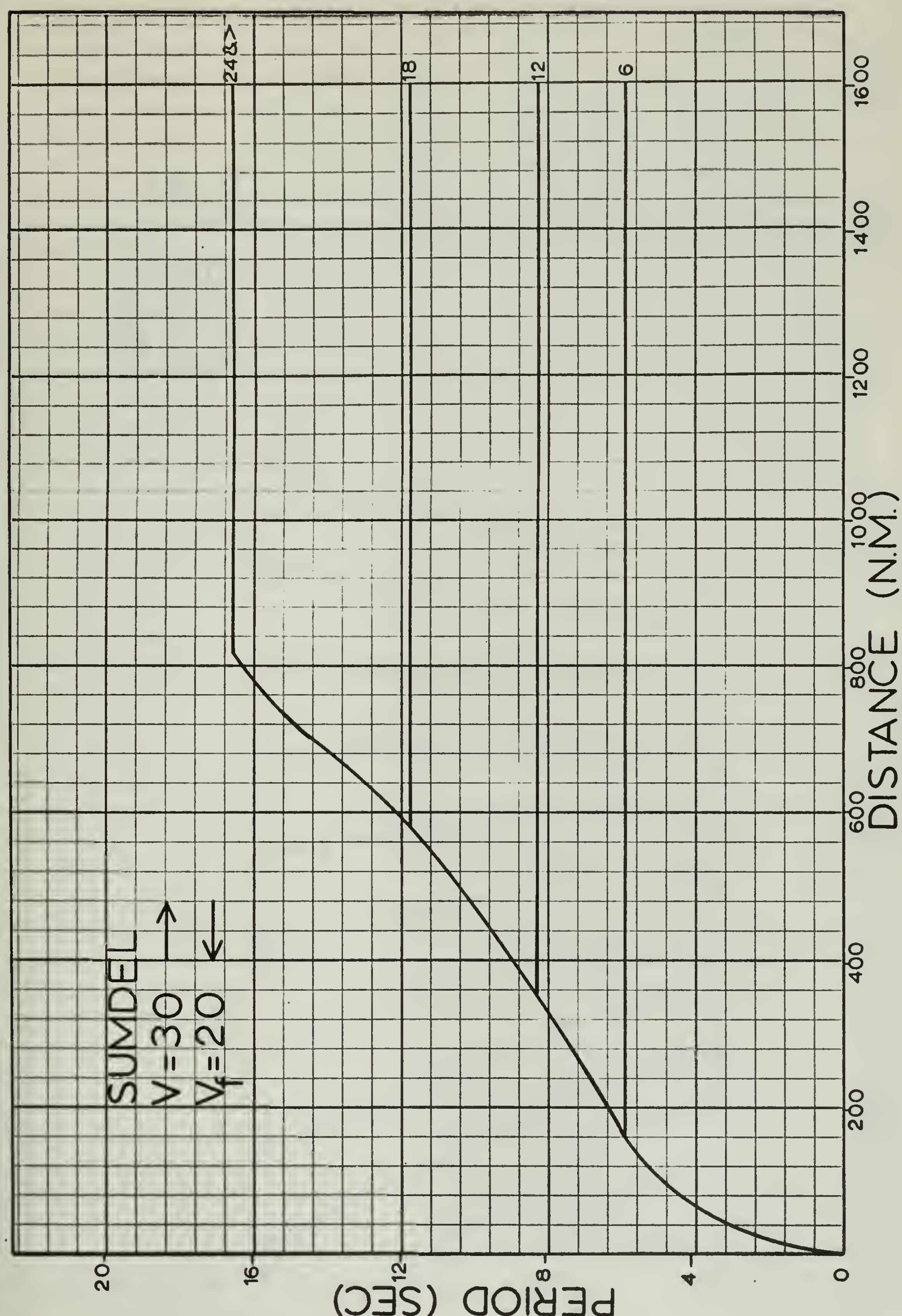
42
48
54
60
66
72

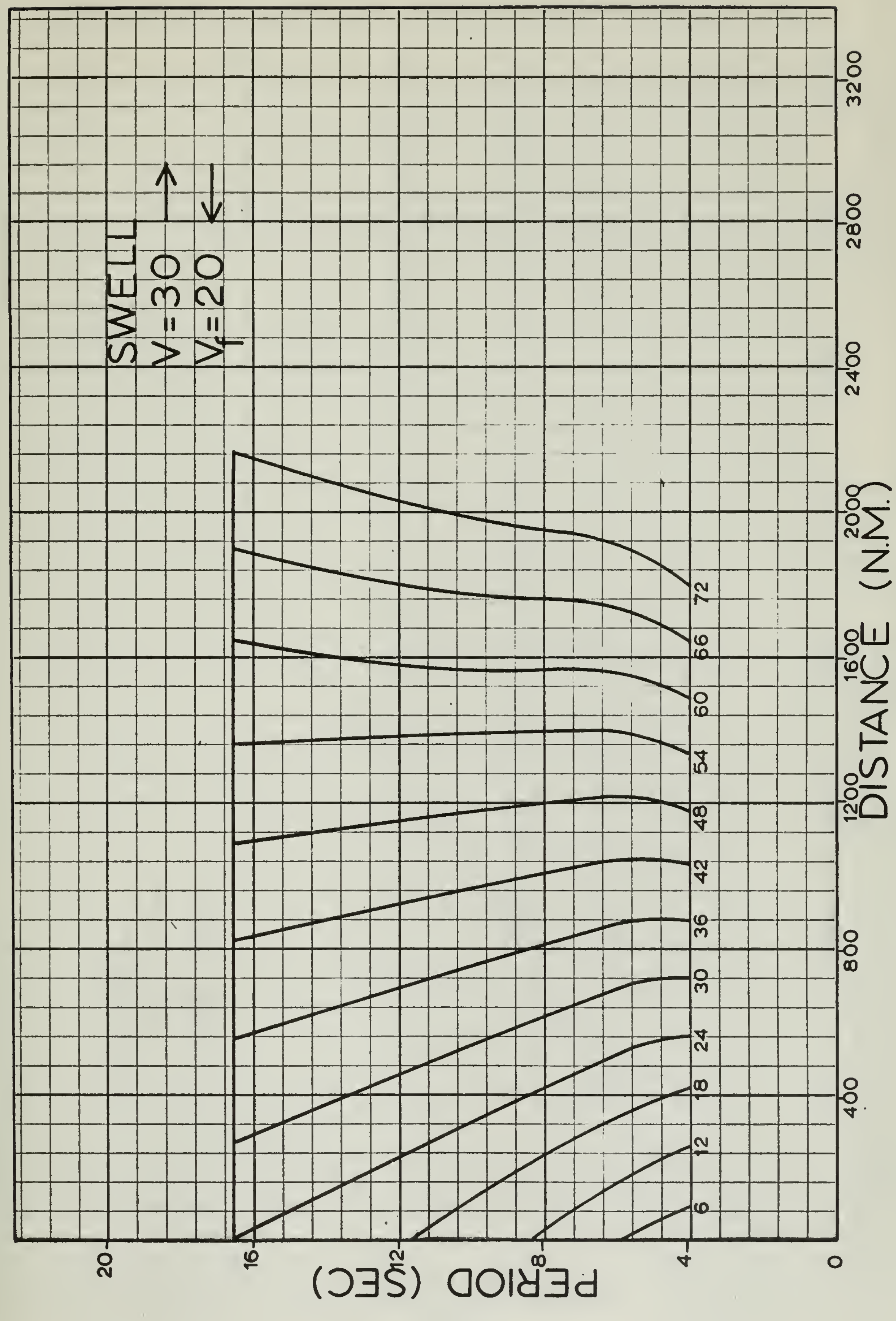

SUMDEL
V = 25
$V_f$ = 25
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
18& >
12
6

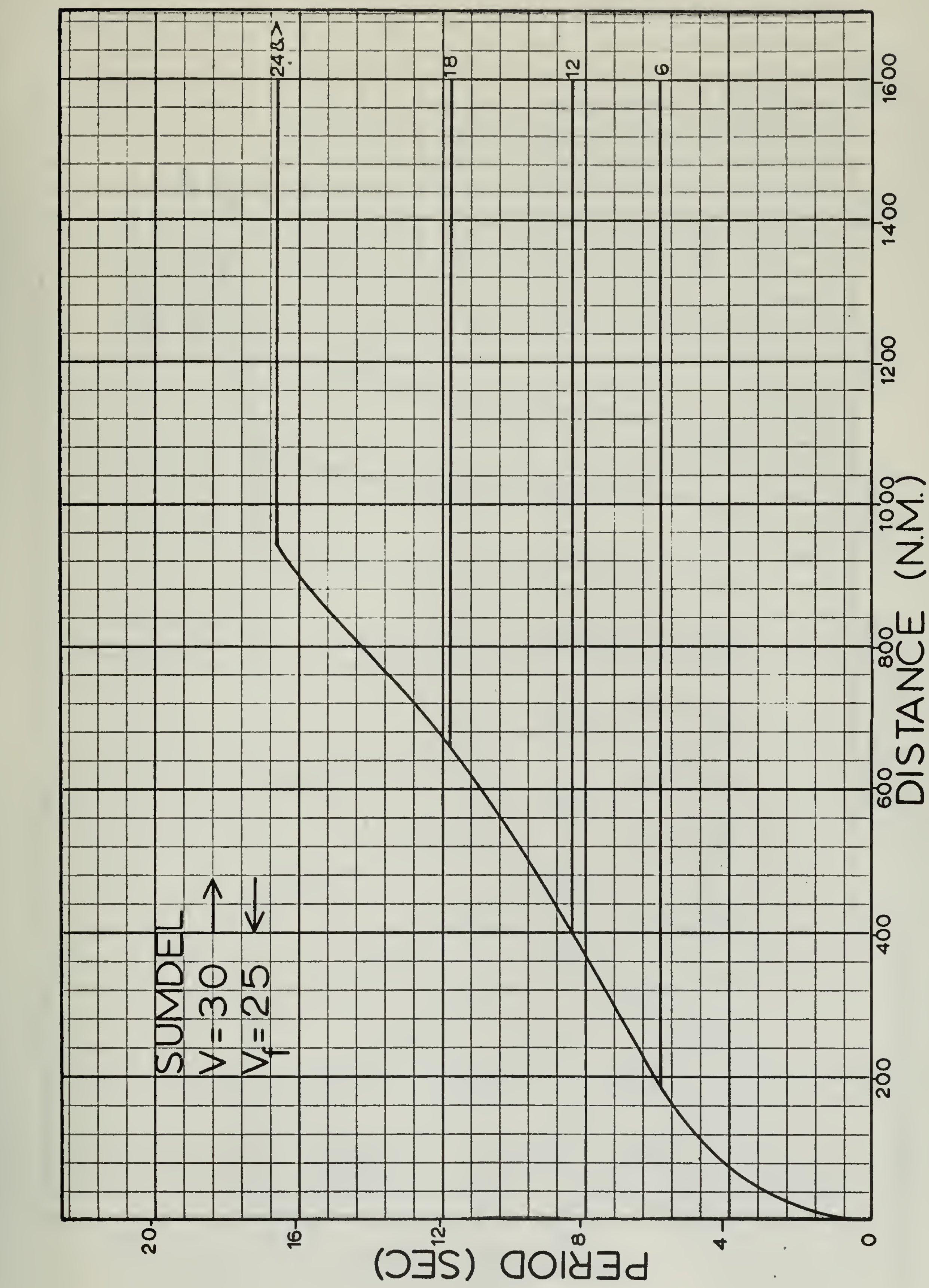

SWELL
V = 25
$V_f$ = 25
PERIOD (SEC)
20
16
12
8
4
0
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)
6
12
18
24
30
36
42
48
54
60
66
72


SUMDEL
V = 30 →
V_f = 15 ←
24 & >
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600

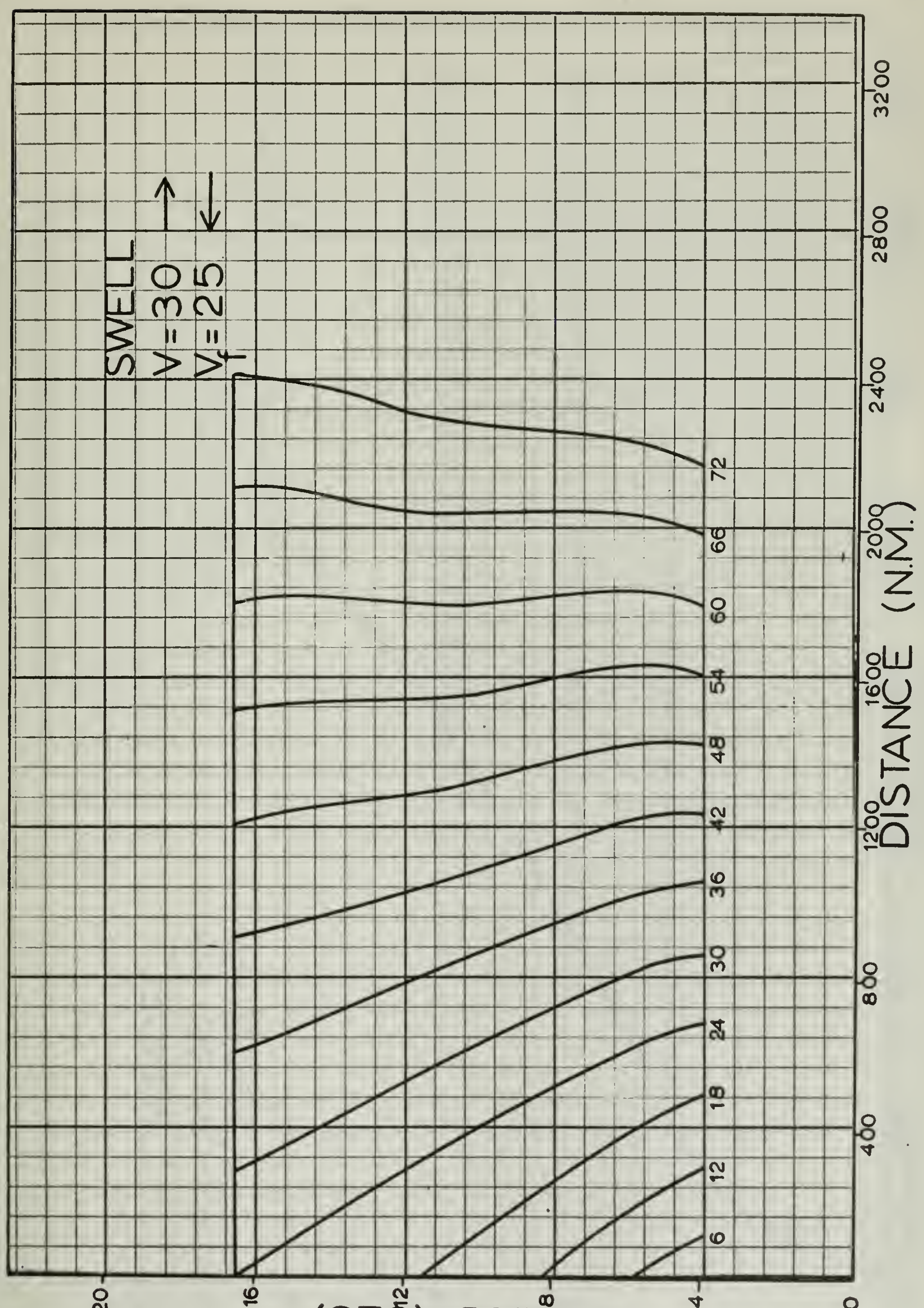

SWELL
V = 30
$V_f$ = 15
DISTANCE (N.M.)
400
800
1200
1600
2000
2400
2800
3200
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72


SUMDEL
V = 30
V_f = 20
24&>
18
12
6
0
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
0
4
8
12
16
20
PERIOD (SEC)


SWELL
V = 30
V_f = 20
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
400
800
1200
1600
2000
2400
2800
3200
6
12
18
24
30
36
42
48
54
60
66
72



SUMDEL
V = 30
V_f = 25
DISTANCE (N.M.)
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
6
12
18
24



SWELL
V = 30
$V_f$ = 25
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
400
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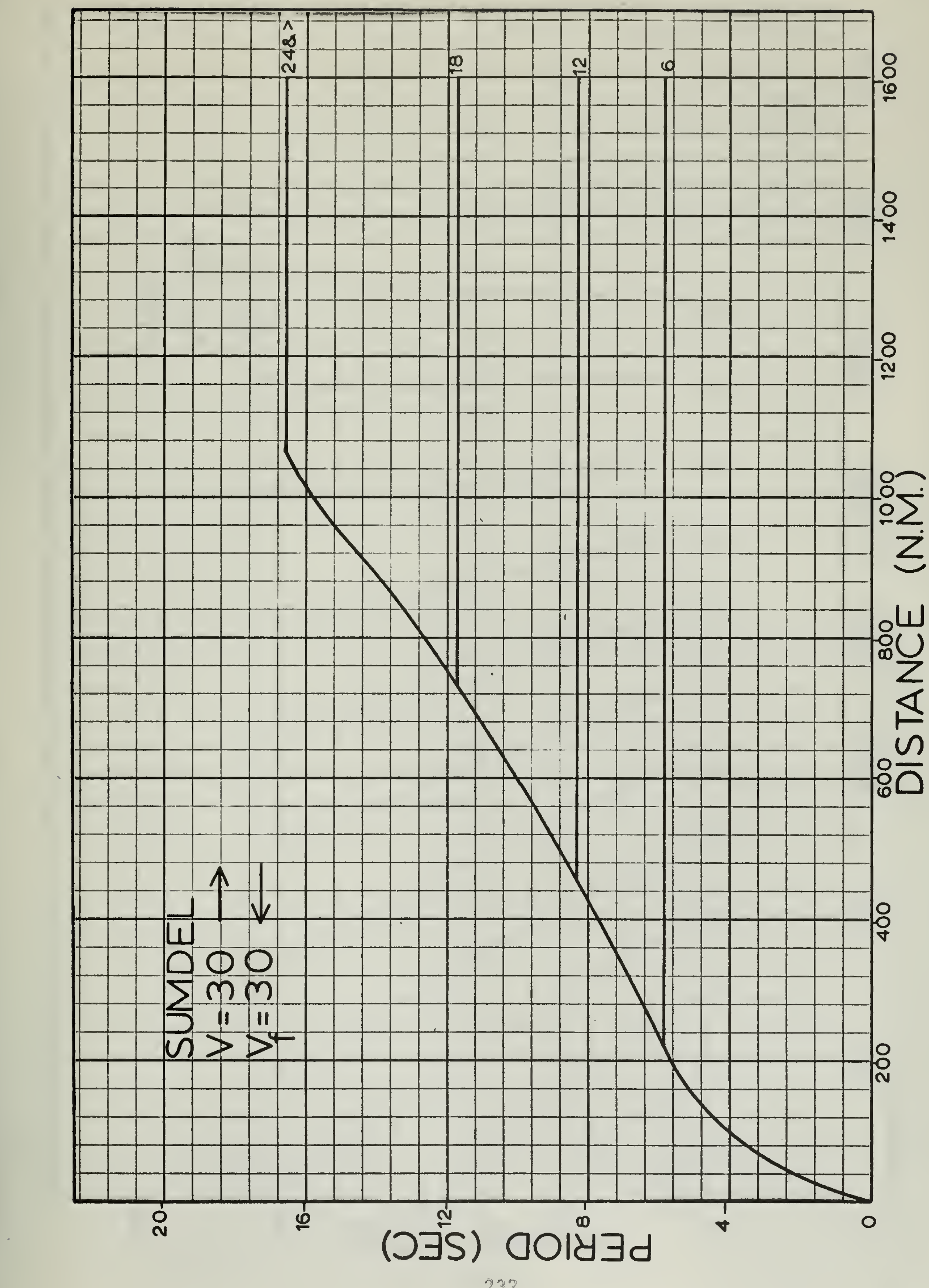
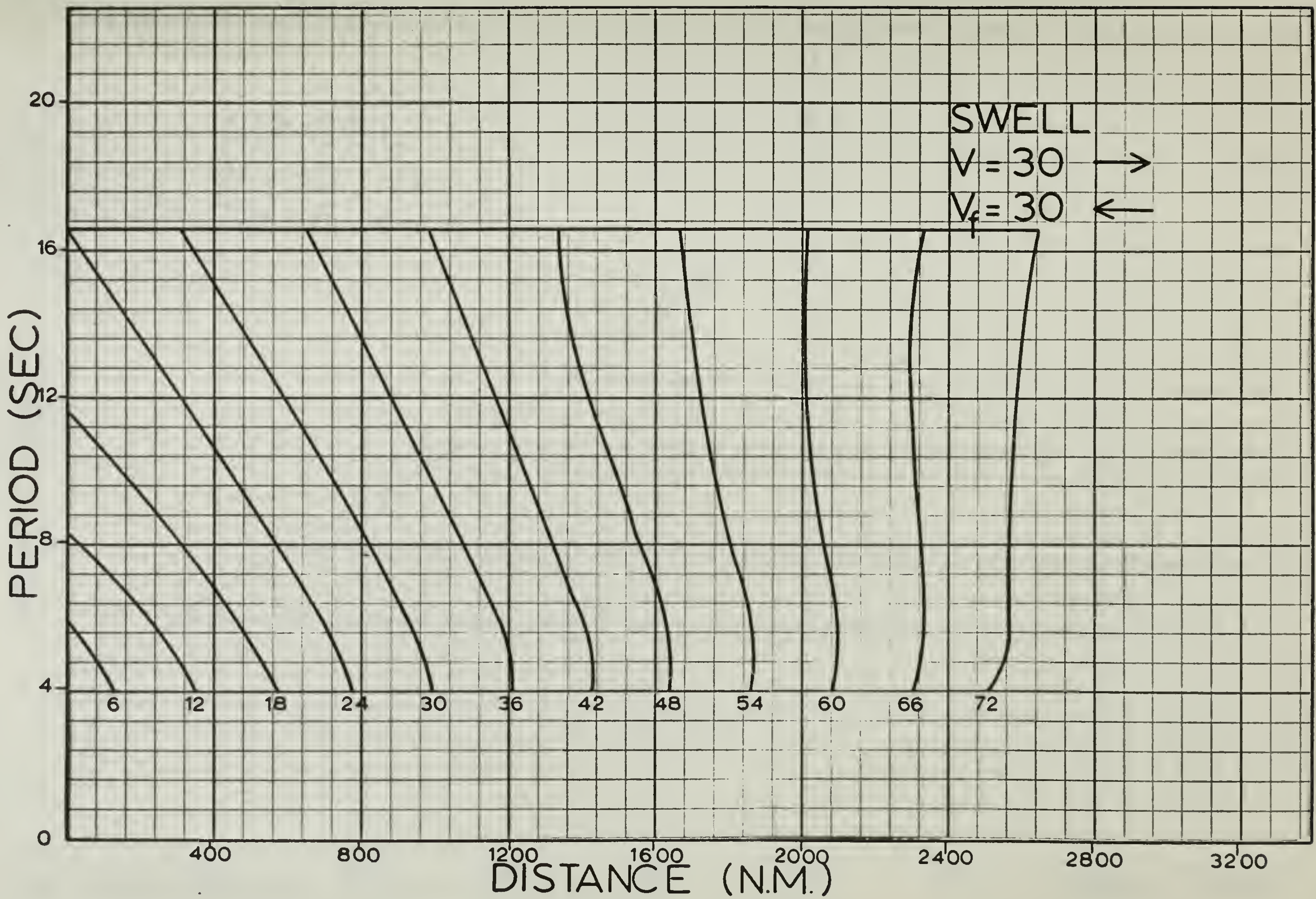
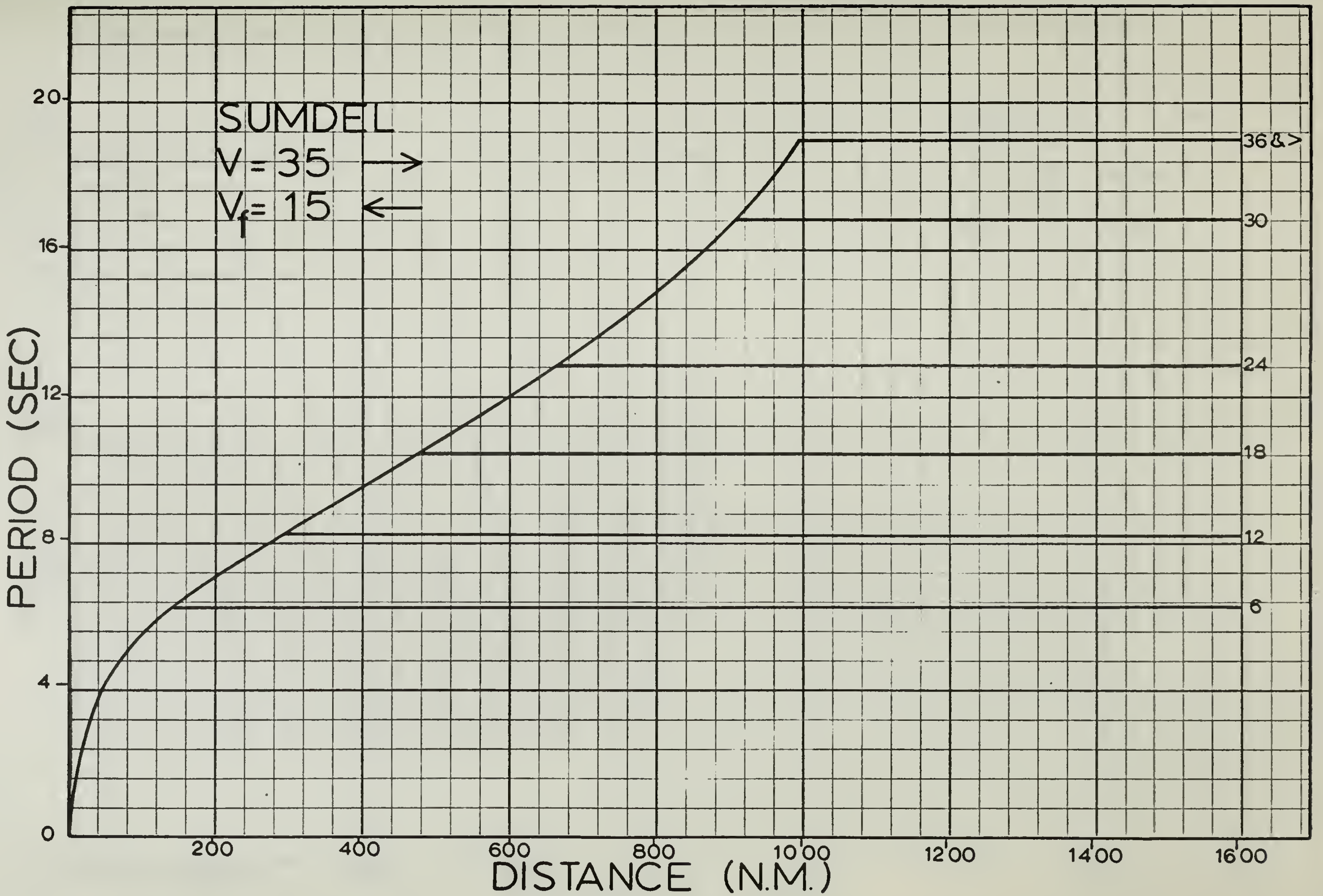
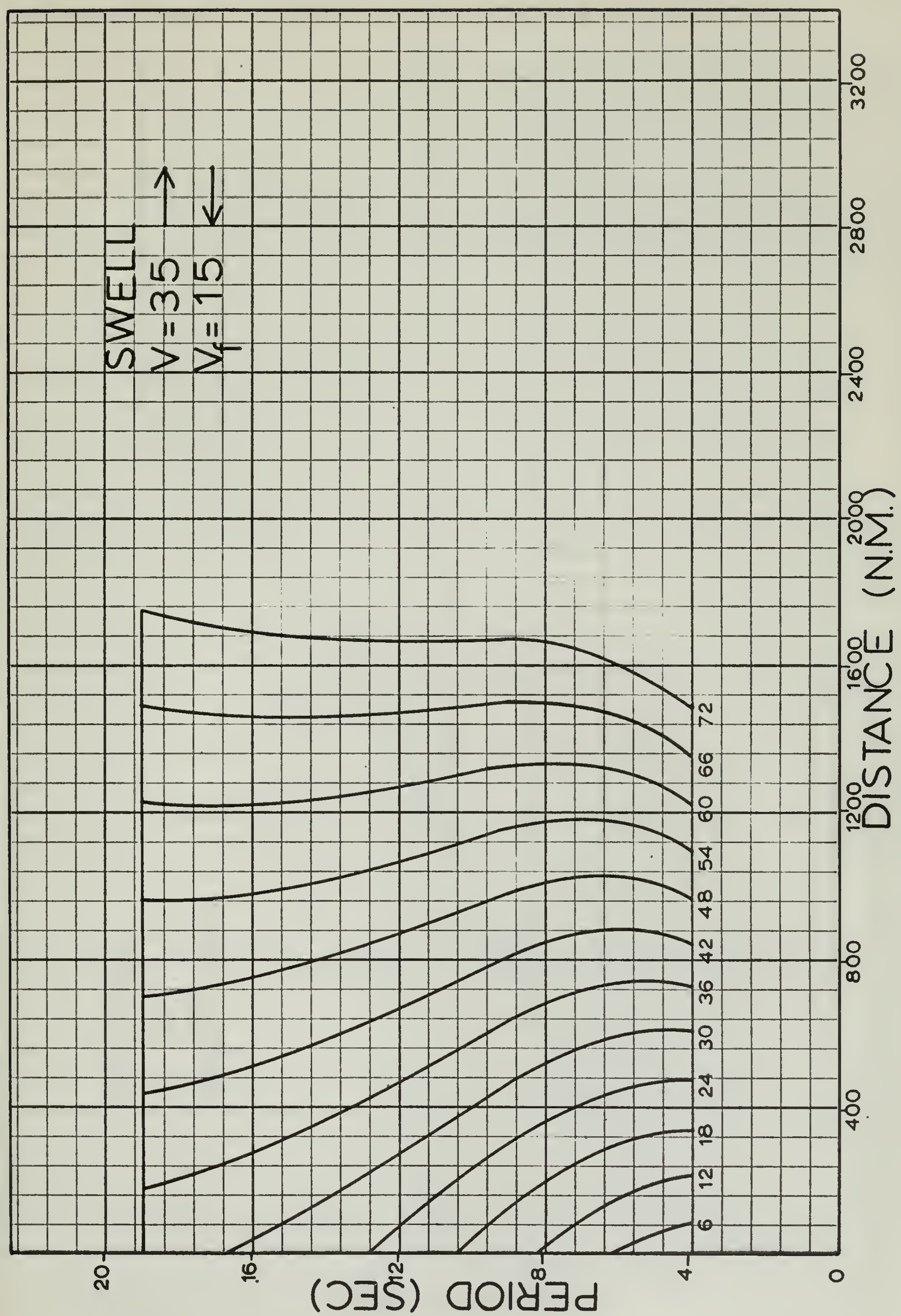
48
54
60
66
72

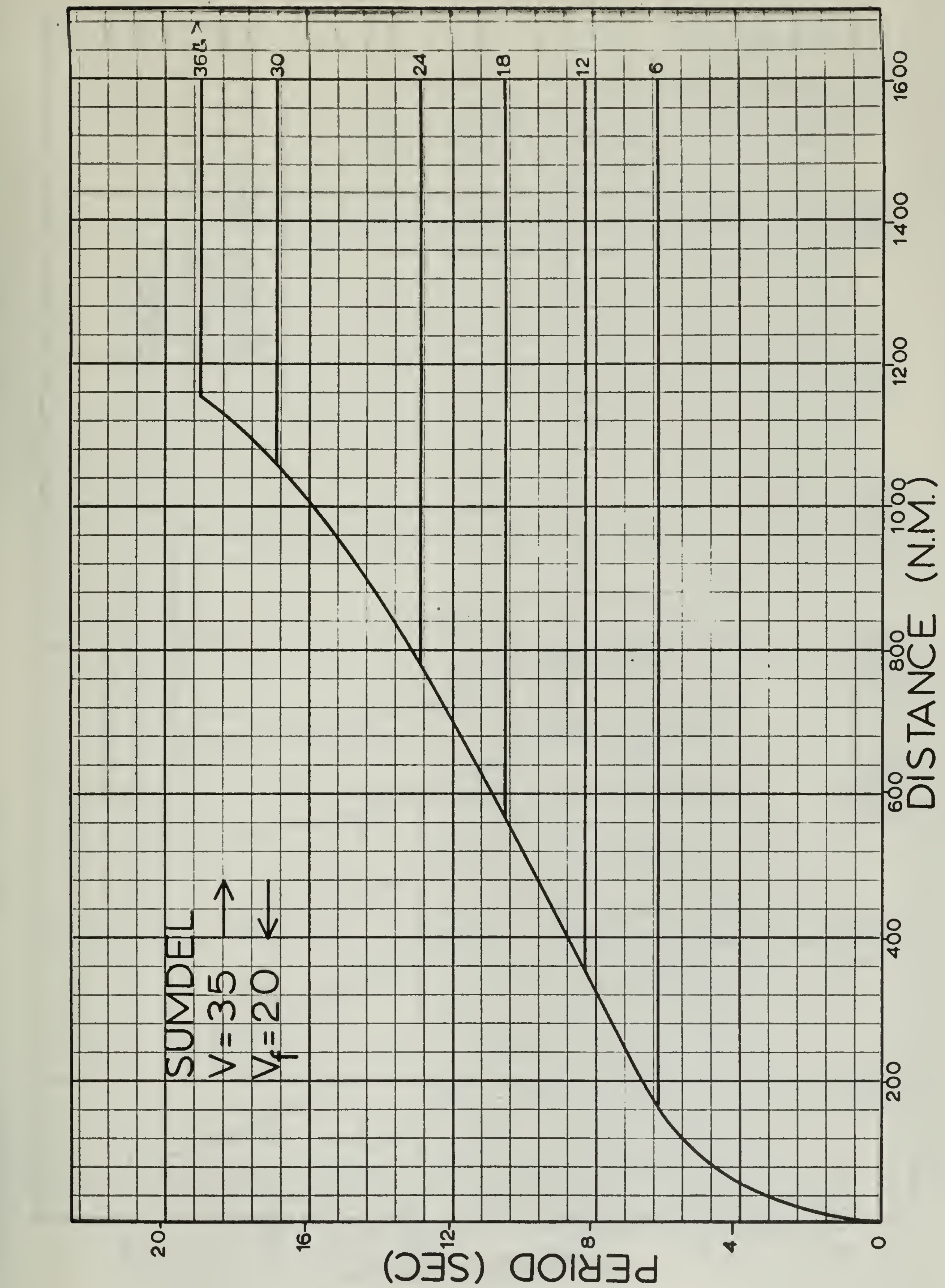

SUMDEL
V = 30
$V_f$ = 30
24& >
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600

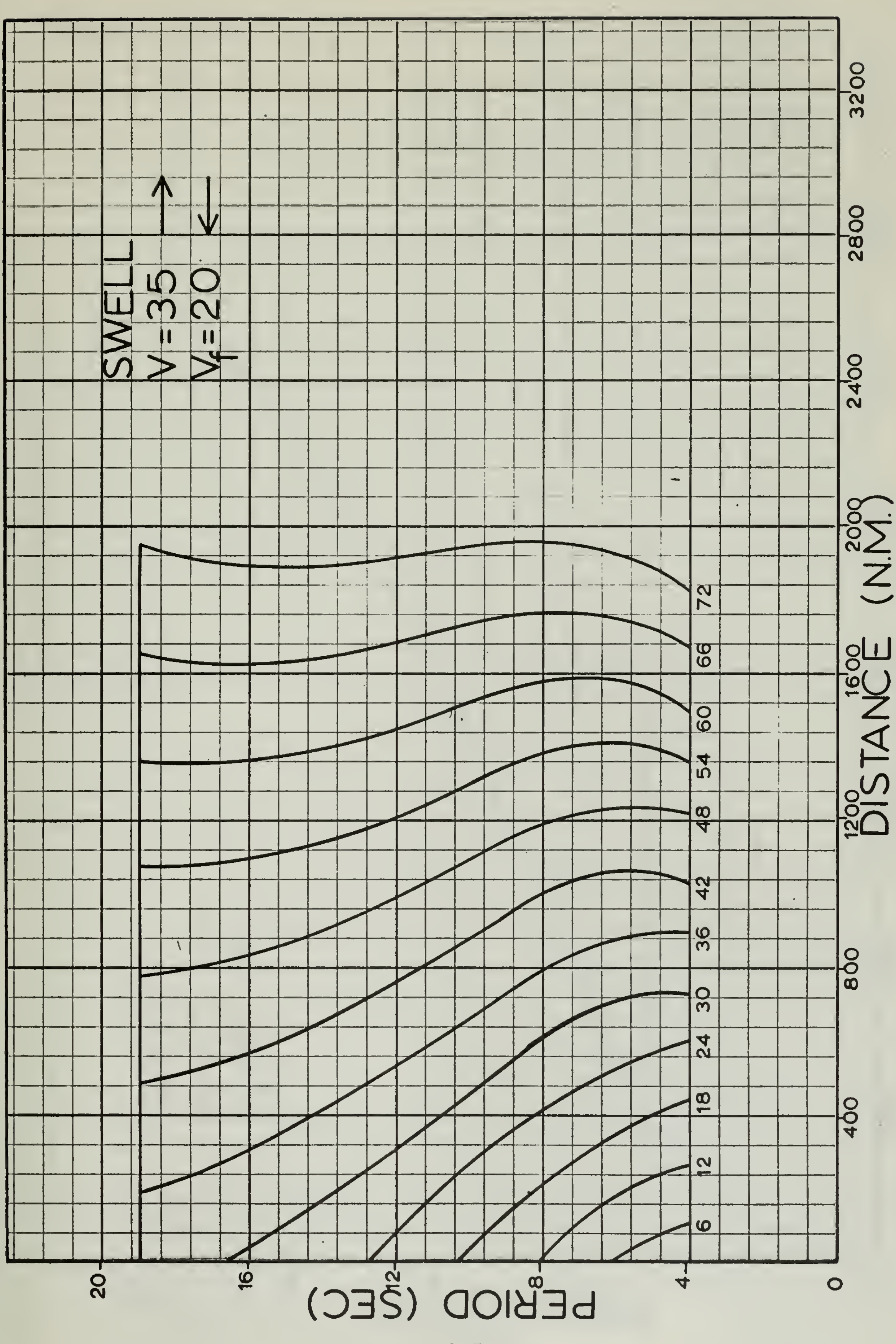

SWELL
V = 30
V_f = 30
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)
0
4
8
12
16
20
PERIOD (SEC)



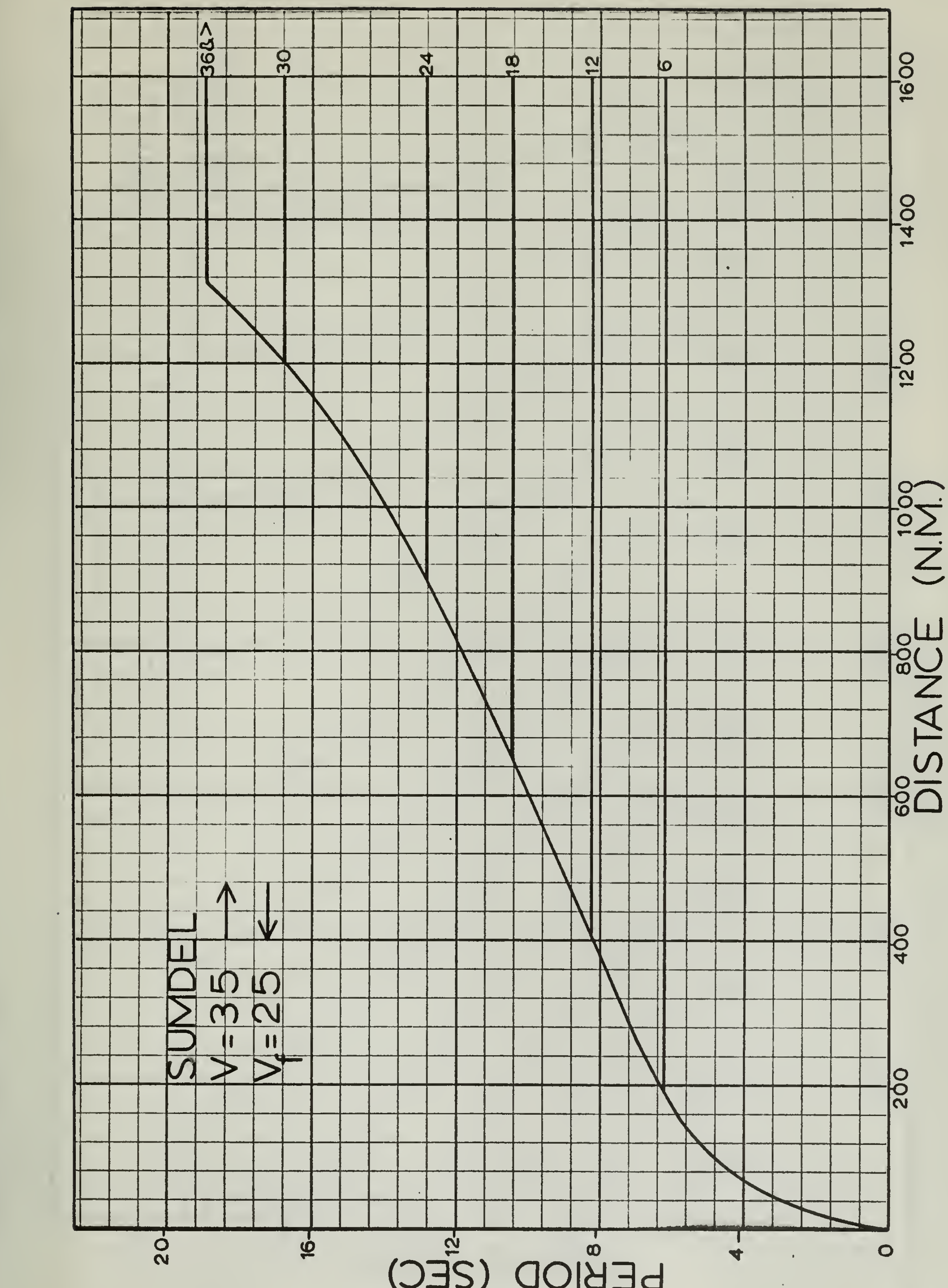
SUMDEL
V = 35 →
V_f = 15 ←
36 & >
30
24
18
12
6
20
16
12
8
4
0
200
400
600
800
1000
1200
1400
1600
PERIOD (SEC)
DISTANCE (N.M.)


SWELL
V = 35
V_f = 15
DISTANCE (N.M.)
PERIOD (SEC)
0
400
800
1200
1600
2000
2400
2800
3200
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72


SUMDEL
V = 35
$V_f$ = 20
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
6
12
18
24
30
36



SWELL
V = 35
$V_f$ = 20
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
400
800
1200
1600
2000
2400
2800
3200
6
12
18
24
30
36
42
48
54
60
66
72


SUMDEL
V = 35 →
Vf = 25 ←
36&>
30
24
18
12
6
PERIOD (SEC)
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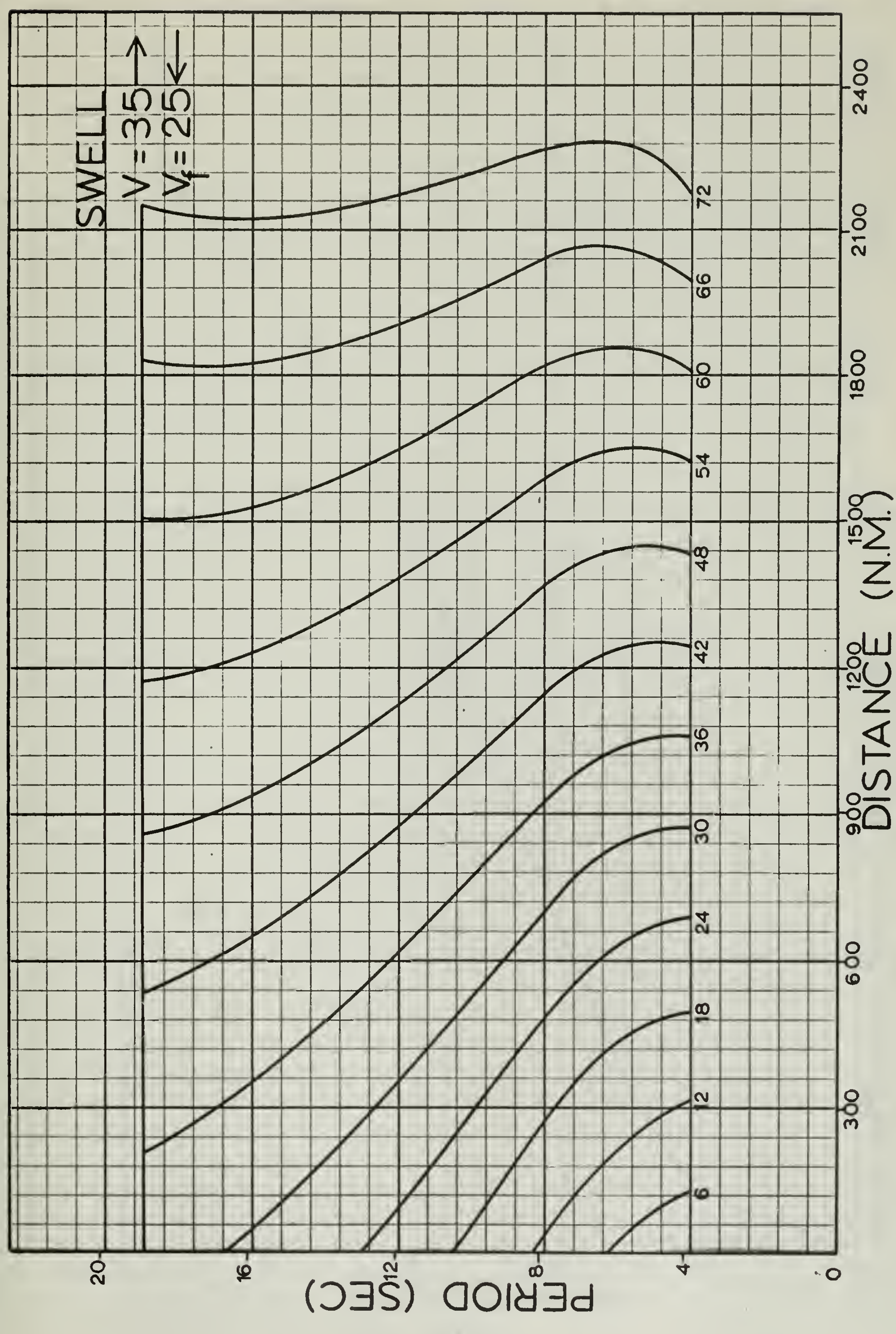
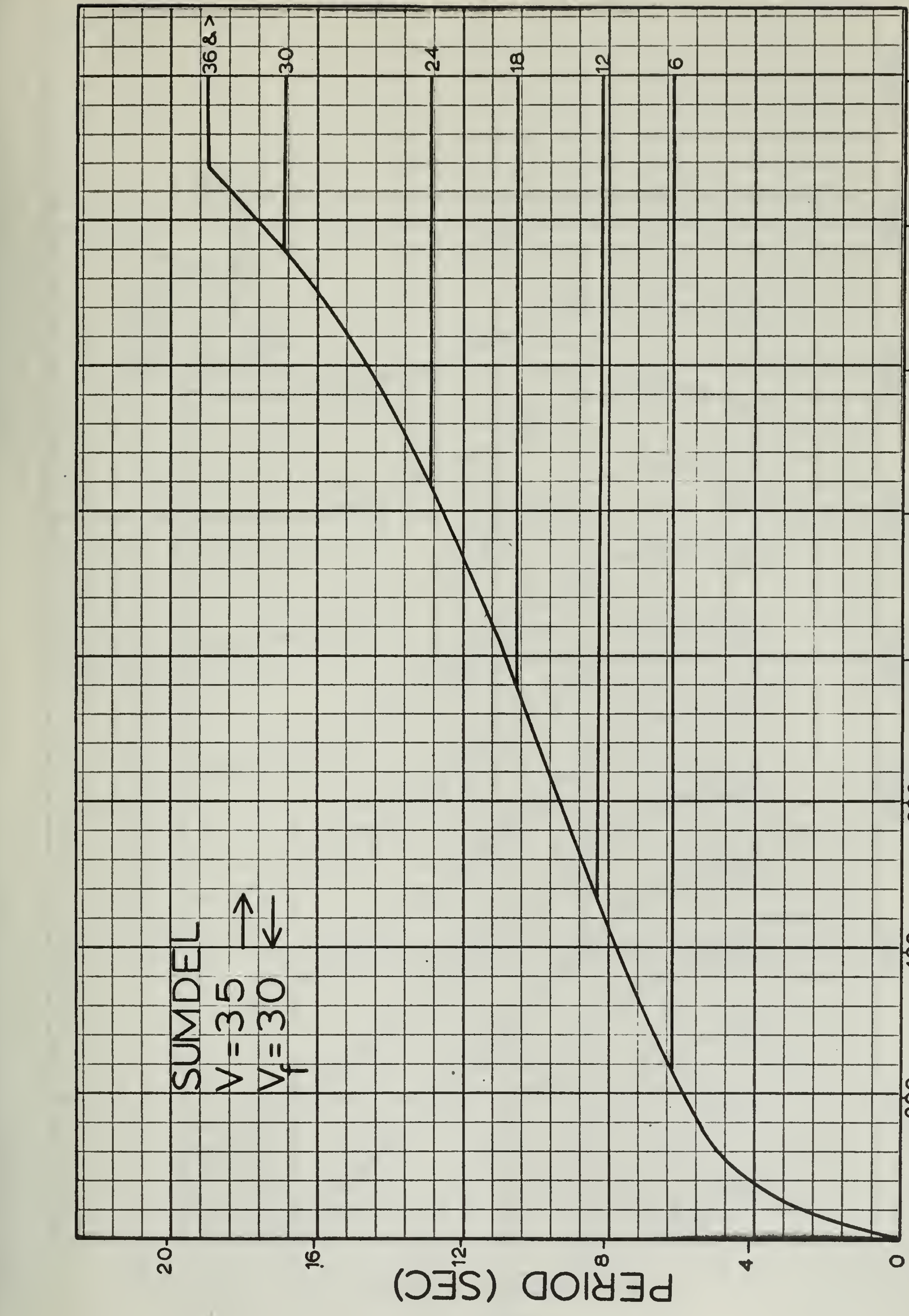
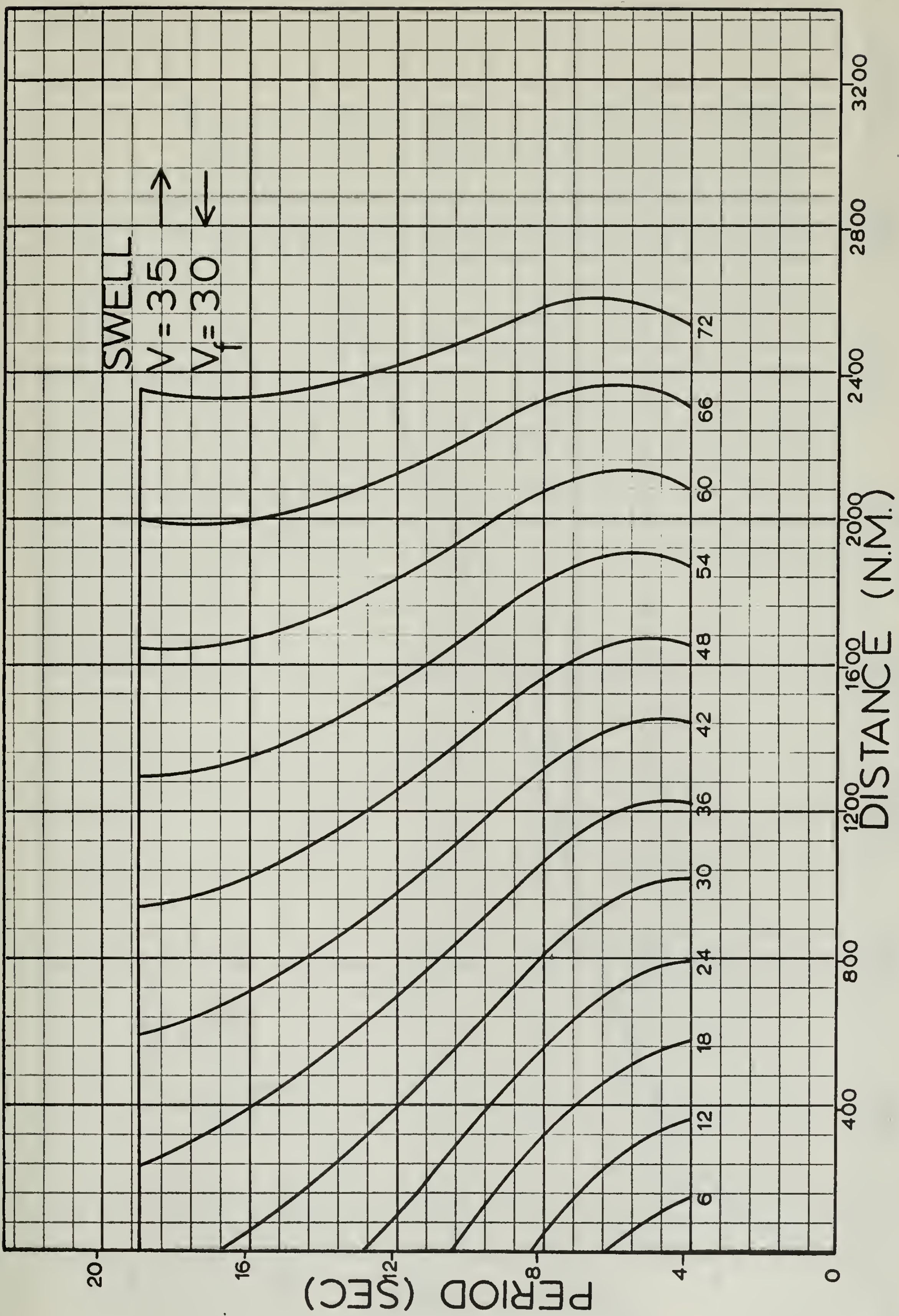
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600


SWELL
V = 35 →
$V_f$ = 25 ←
DISTANCE (N.M.)
300
600
900
1200
1500
1800
2100
2400
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72


SUMDEL
V = 35 →
V_f = 30 ←
36 & >
30
24
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600


SWELL
V = 35
$V_f$ = 30
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
400
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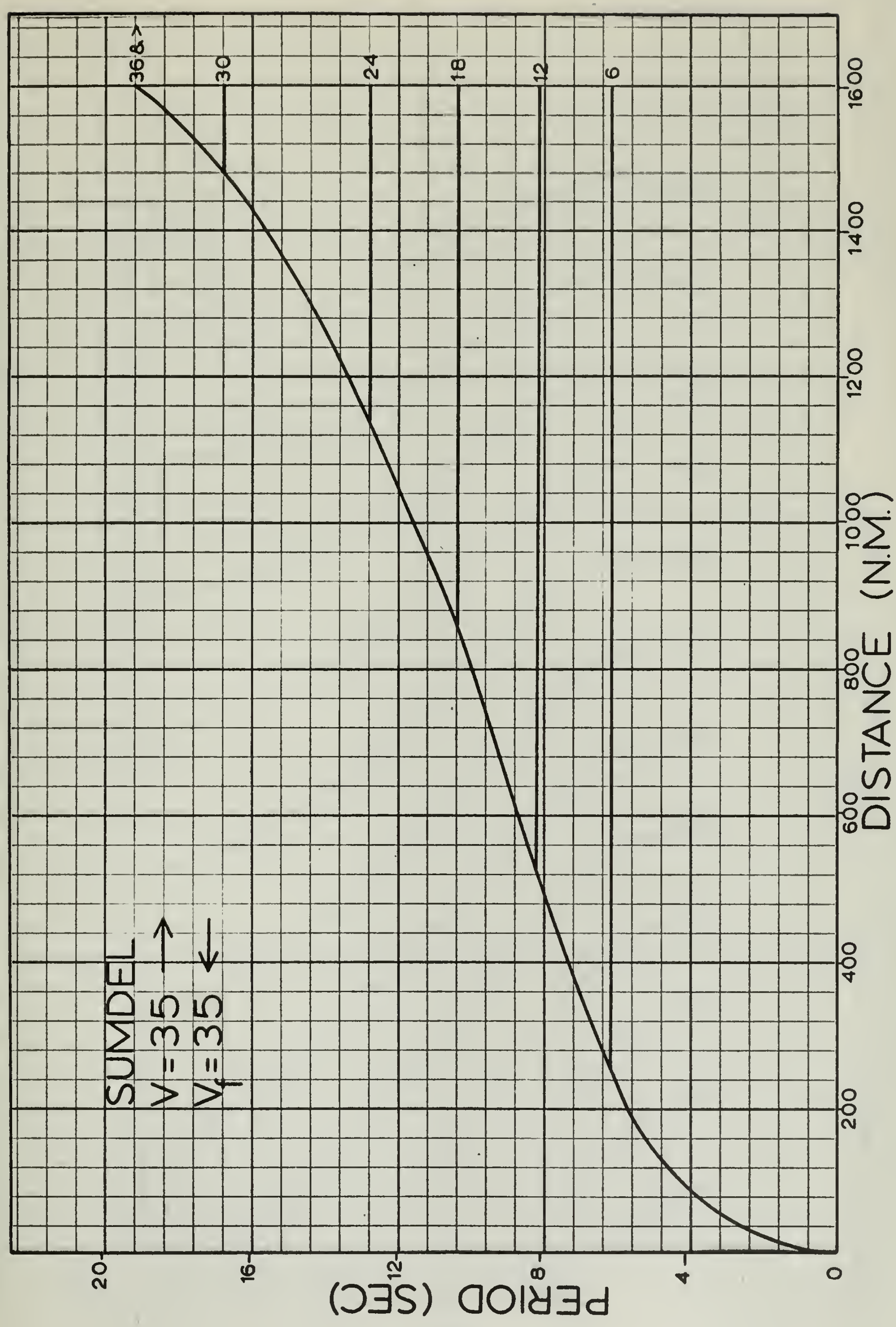
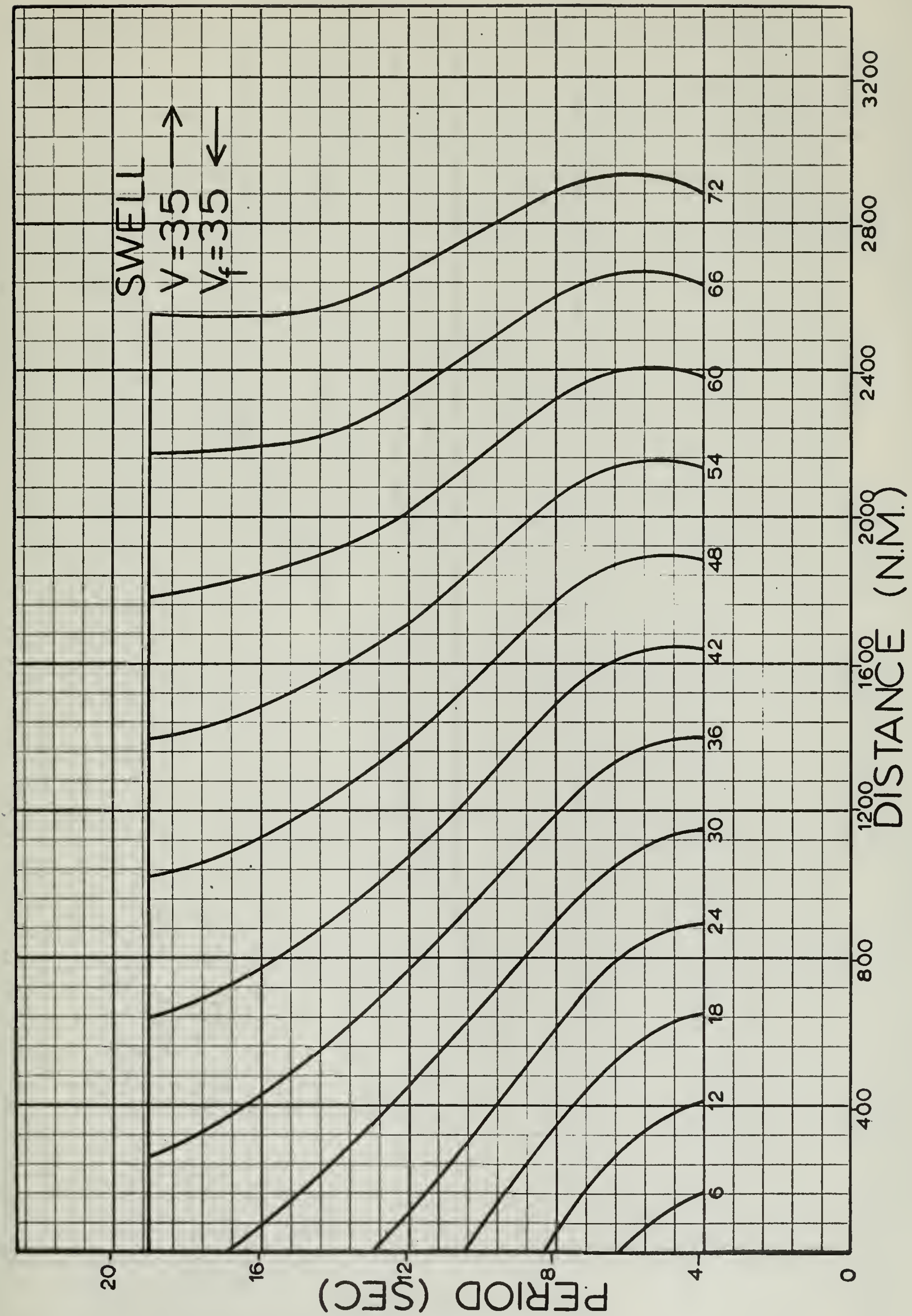
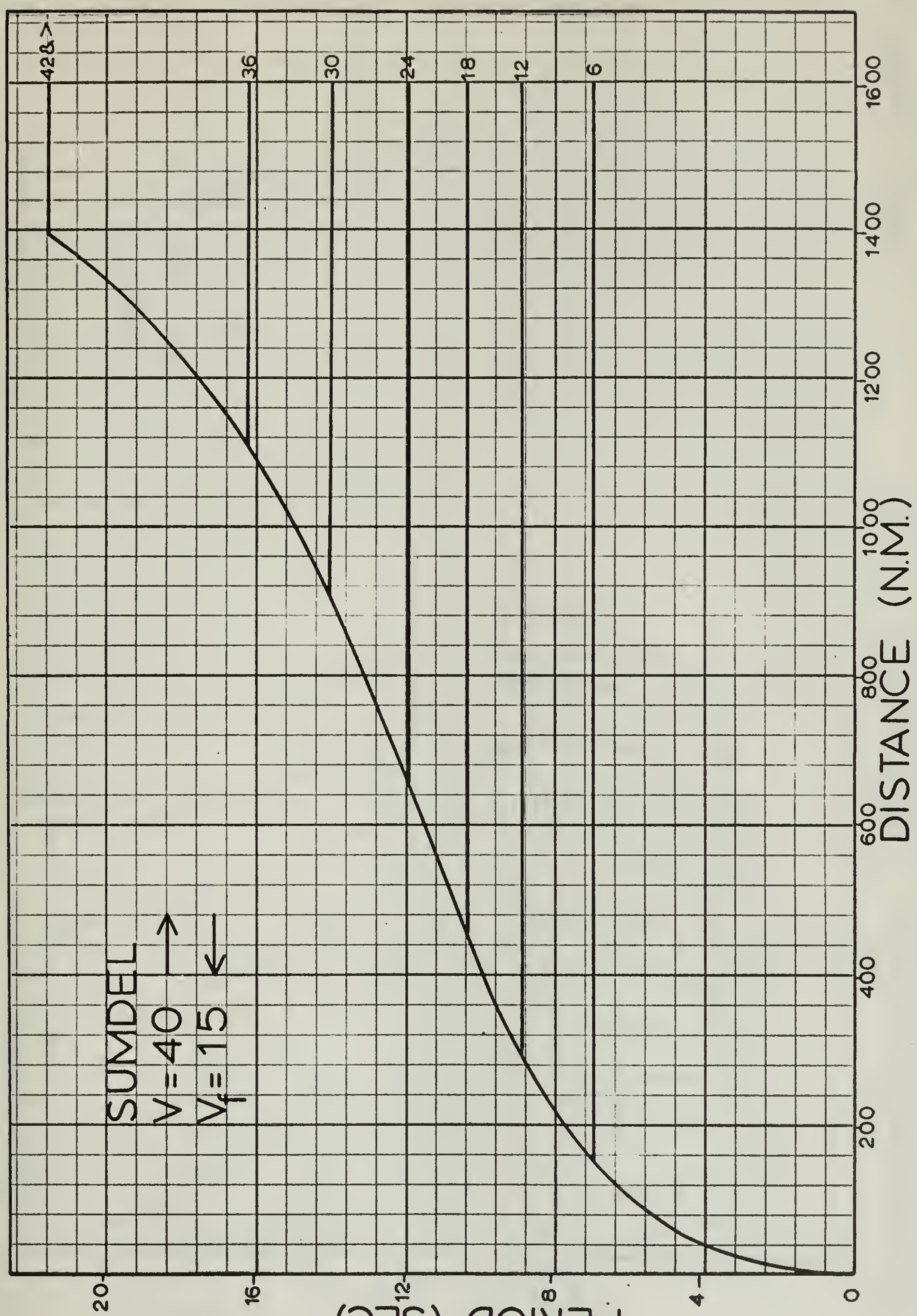
48
54
60
66
72

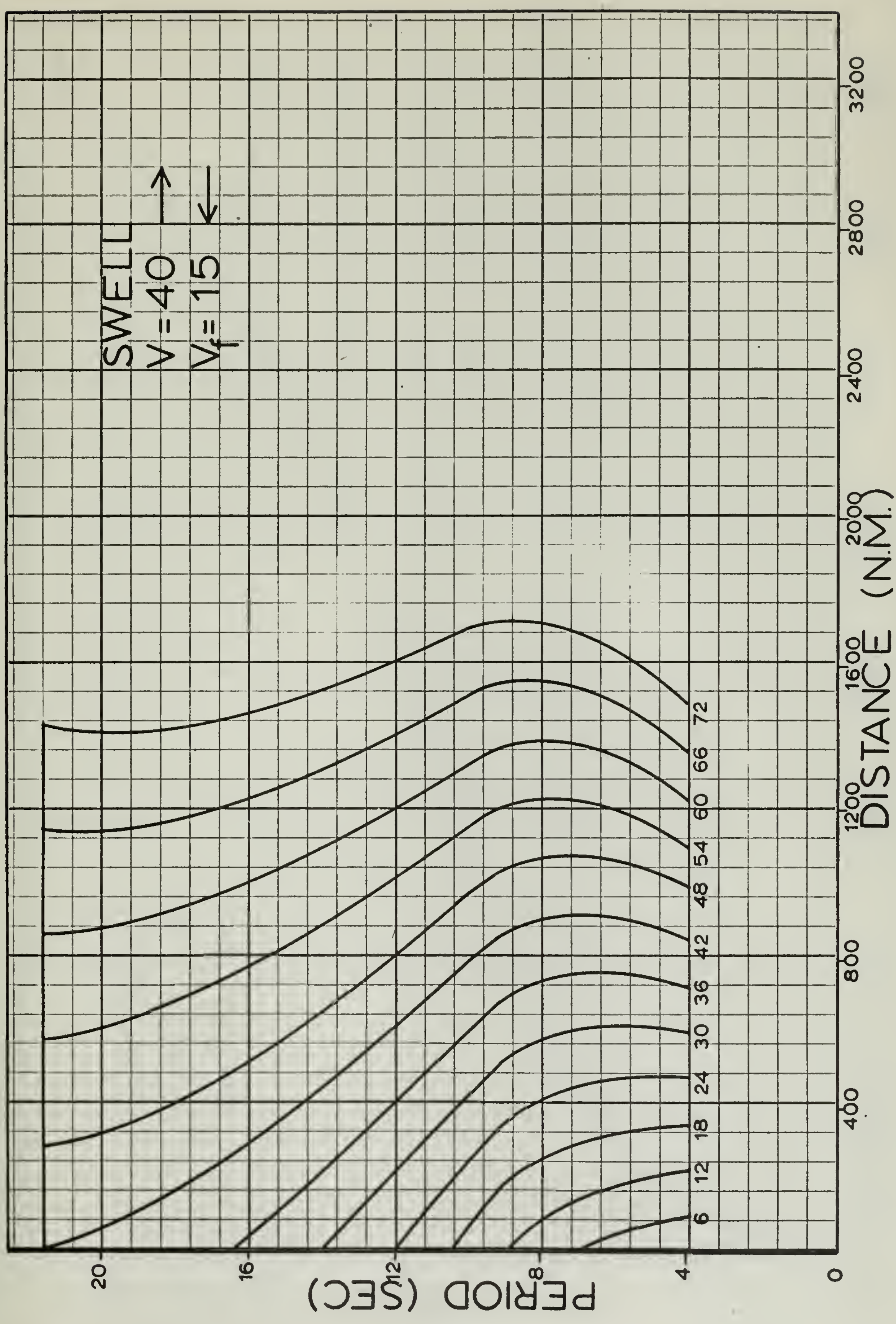


SUMDEL
V = 35 →
$V_f$ = 35 ←
36 & >
30
24
18
12
6
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600

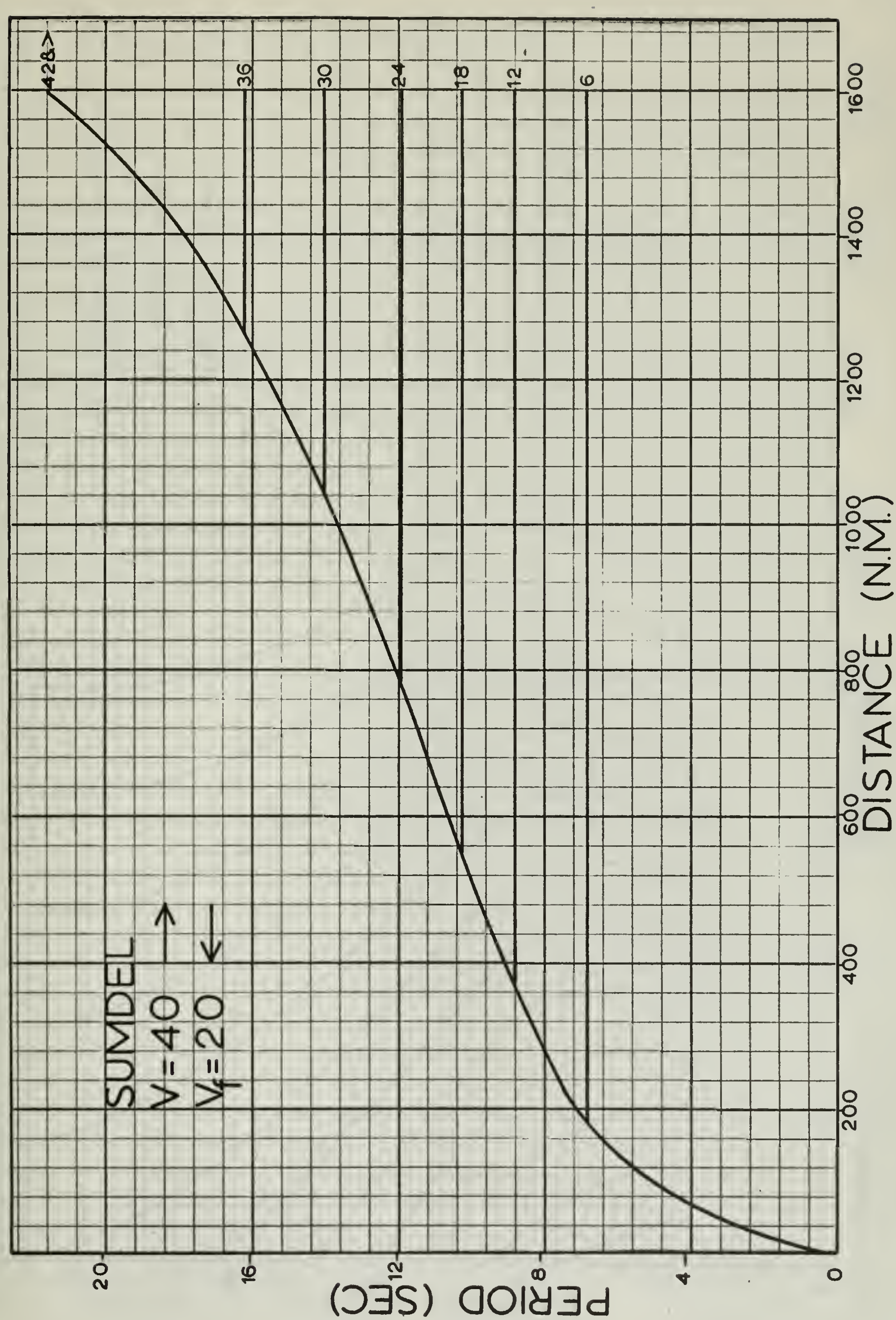

SWELL
V = 35 →
$V_f$ = 35 ←
6
12
18
24
30
36
42
48
54
60
66
72
PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
400
800
1200
1600
2000
2400
2800
3200



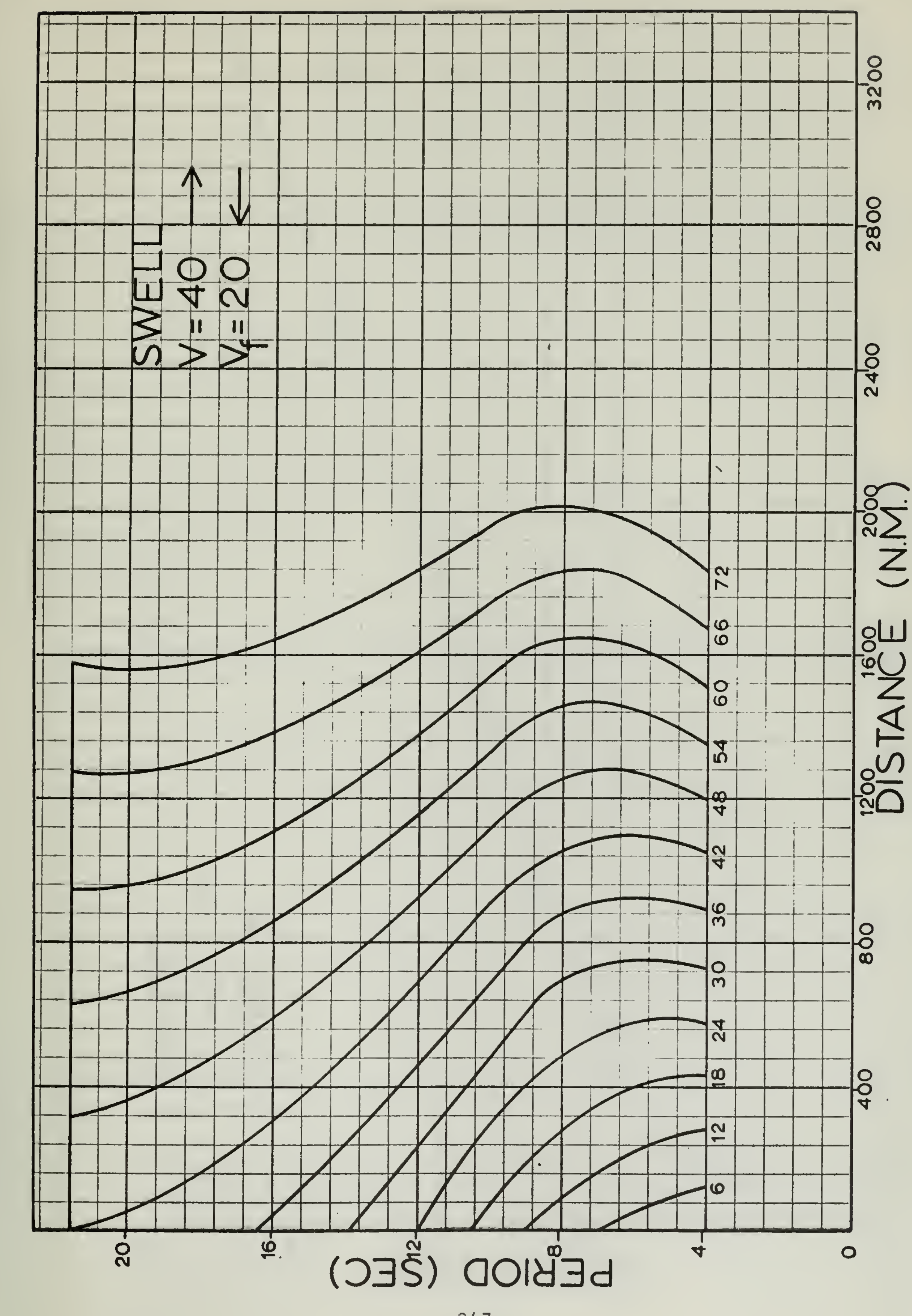
SUMDEL
V = 40 →
$V_f$ = 15 ←
42 & >
36
30
24
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600



SWELL
V = 40
$V_f$ = 15
DISTANCE (N.M.)
PERIOD (SEC)
0
400
800
1200
1600
2000
2400
2800
3200
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72



SUMDEL
V = 40 →
V_f = 20 ←
DISTANCE (N.M.)
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
6
12
18
24
30
36
42&>


SWELL
V = 40
$V_f$ = 20
DISTANCE (N.M.)
PERIOD (SEC)
0
4
8
12
16
20
400
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1200
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2400
2800
3200
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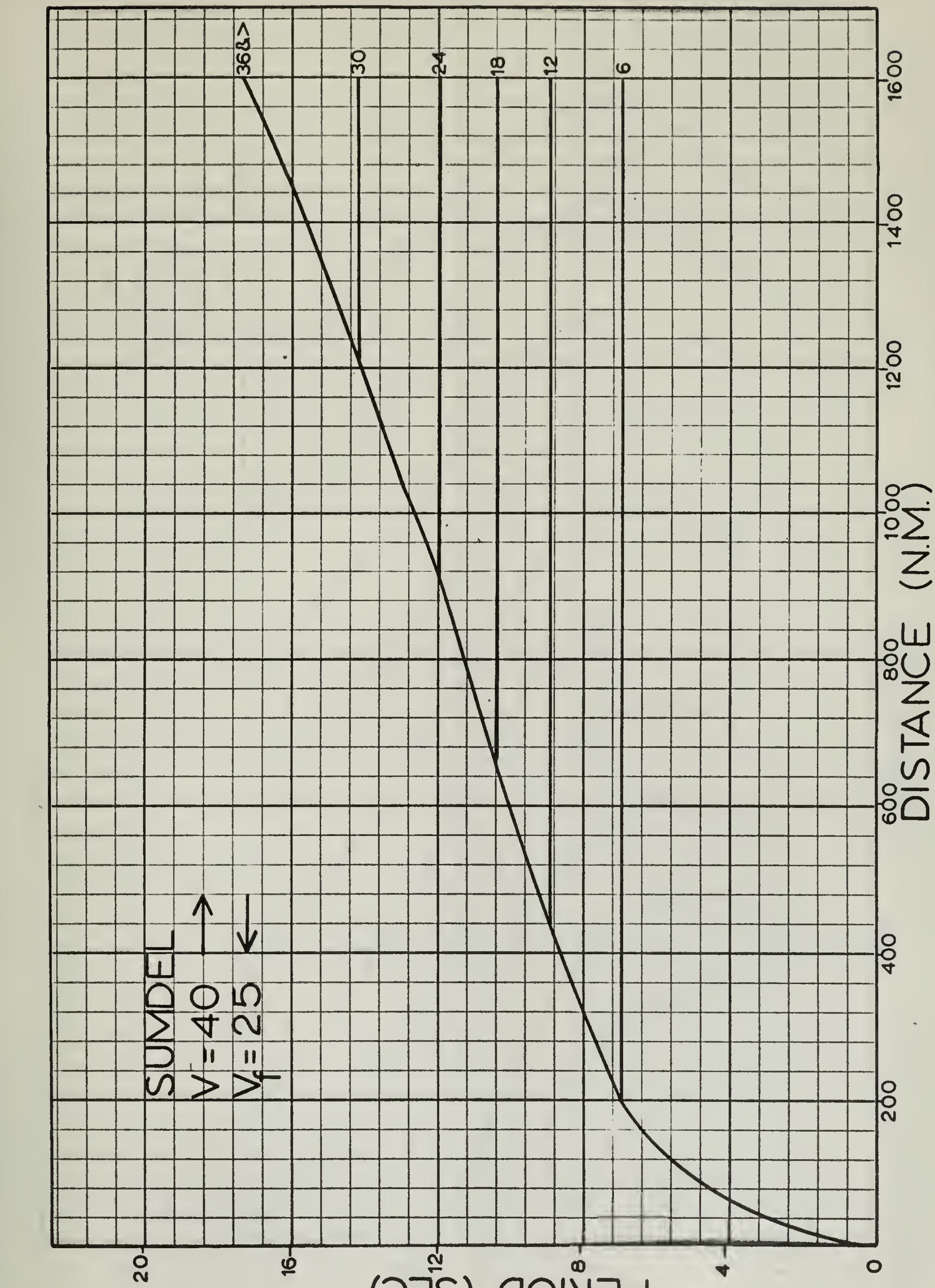
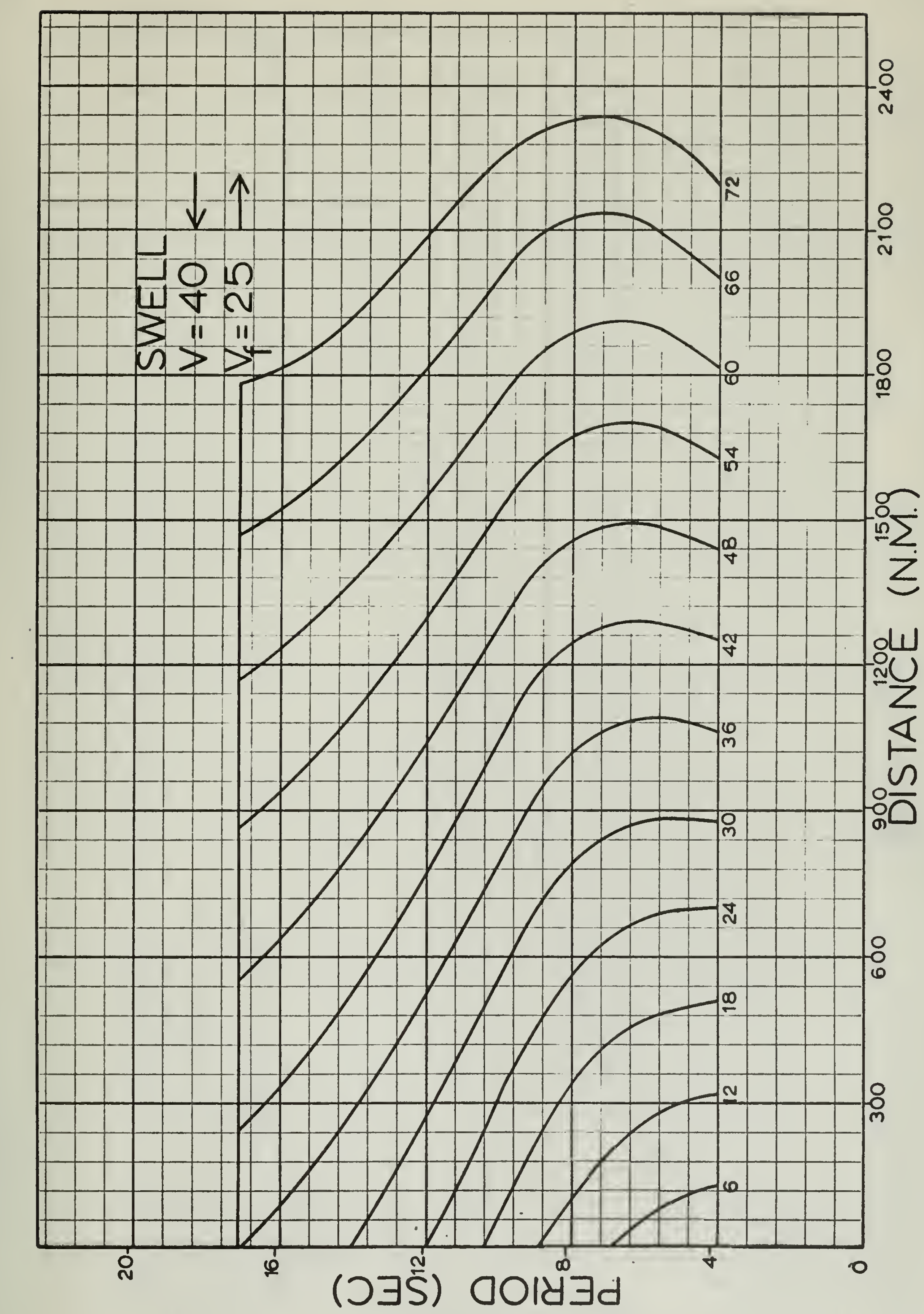
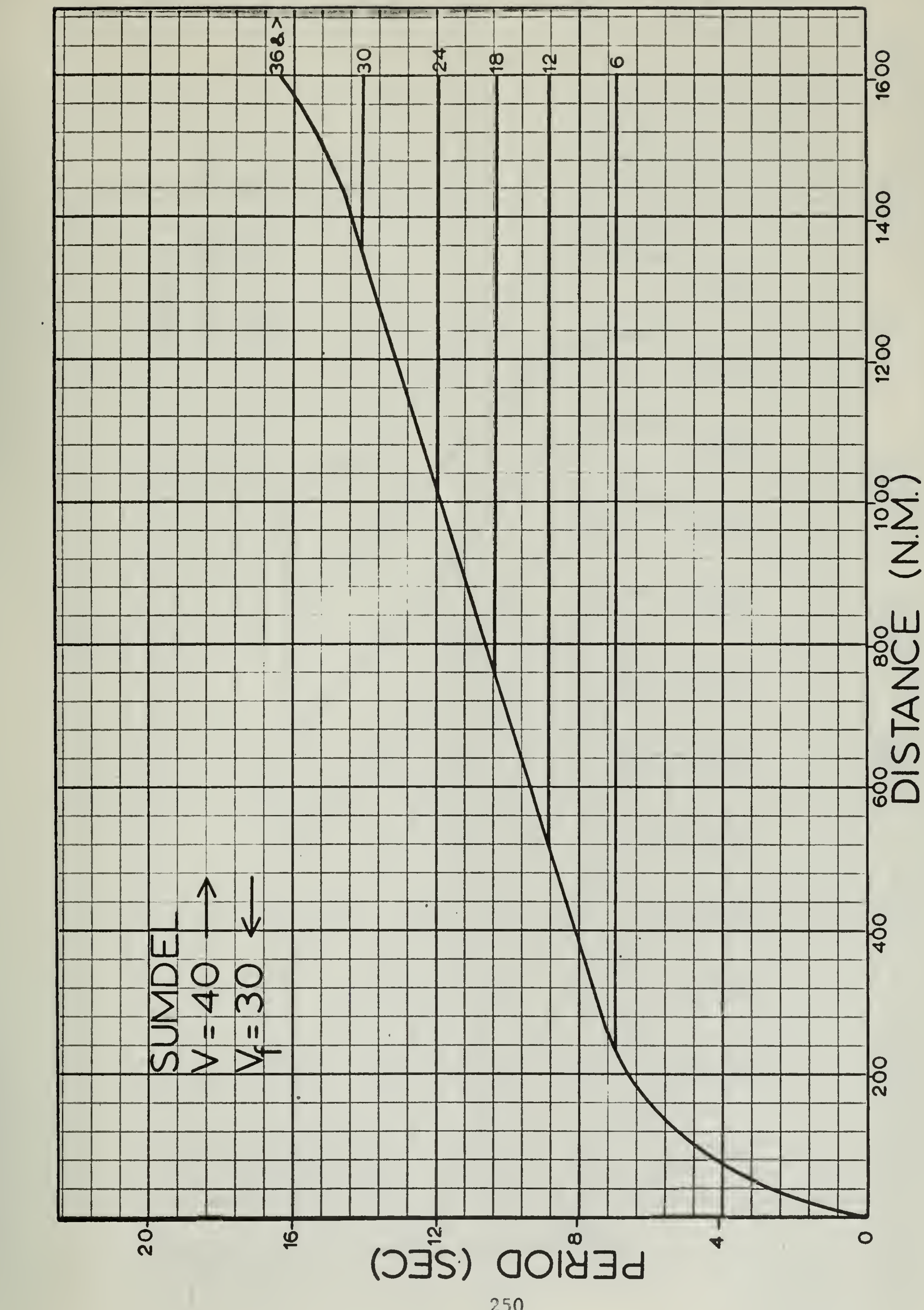
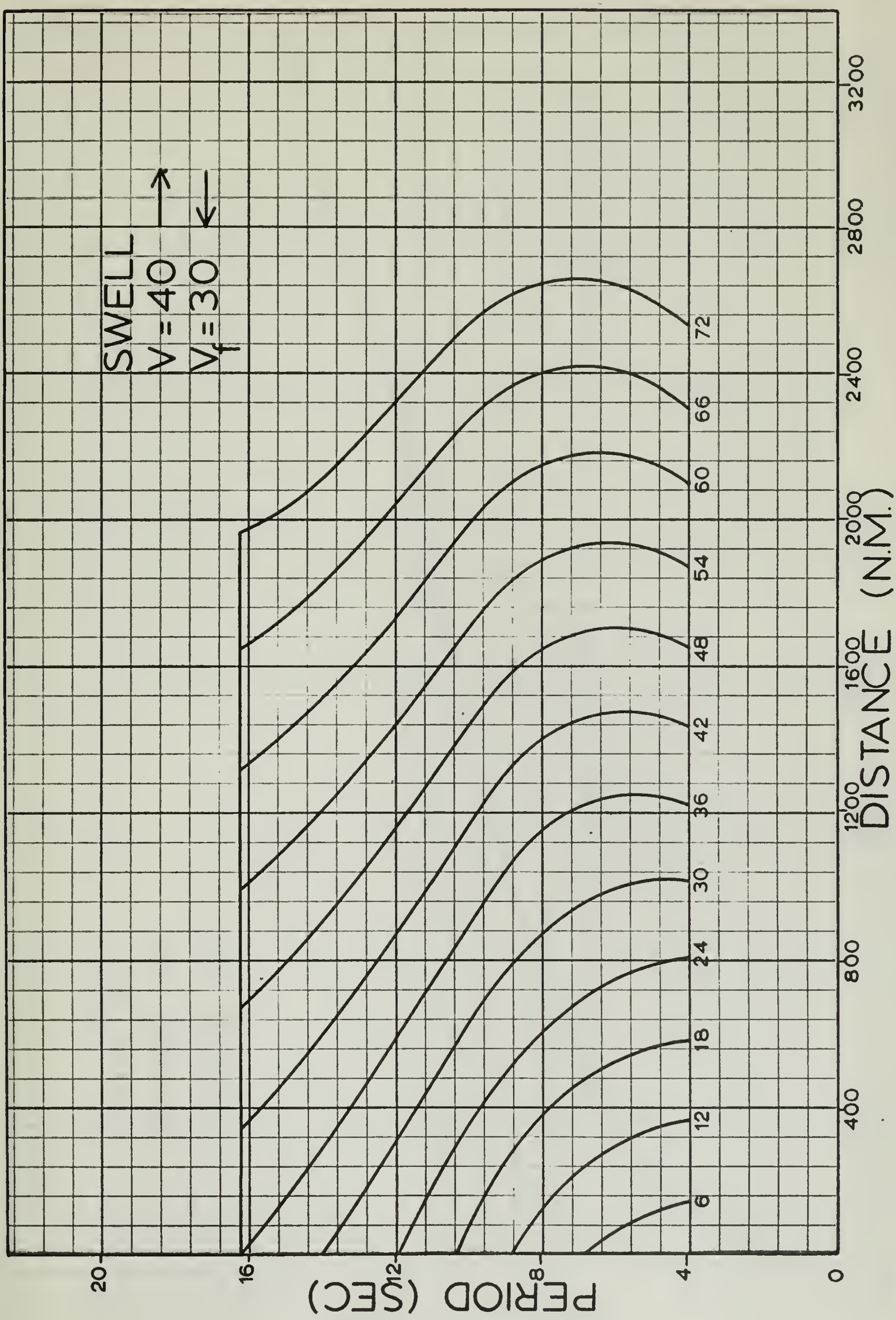
48
54
60
66
72

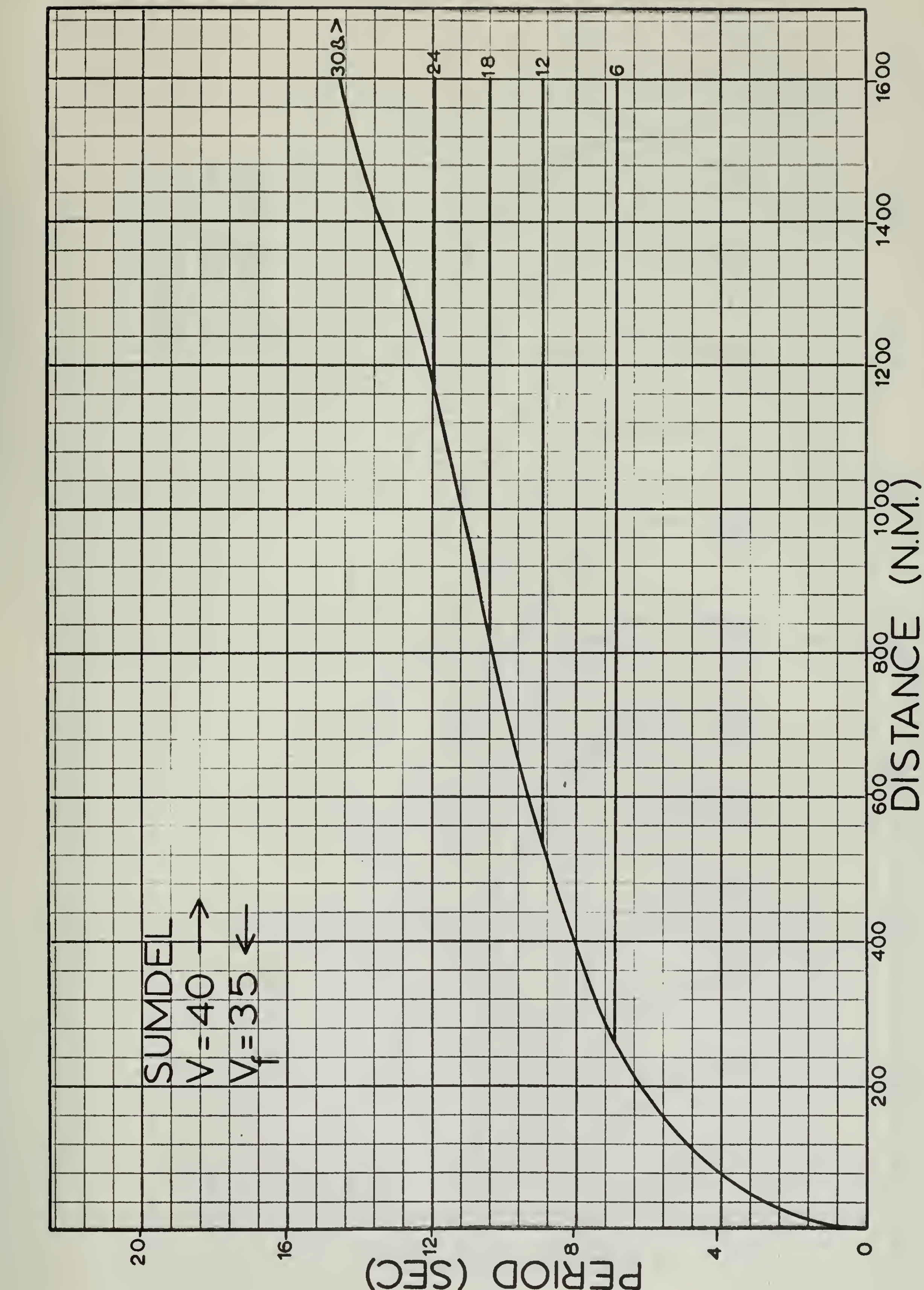

SUMDEL
V = 40 →
V_f = 25 ←
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
6
12
18
24
30
36&>

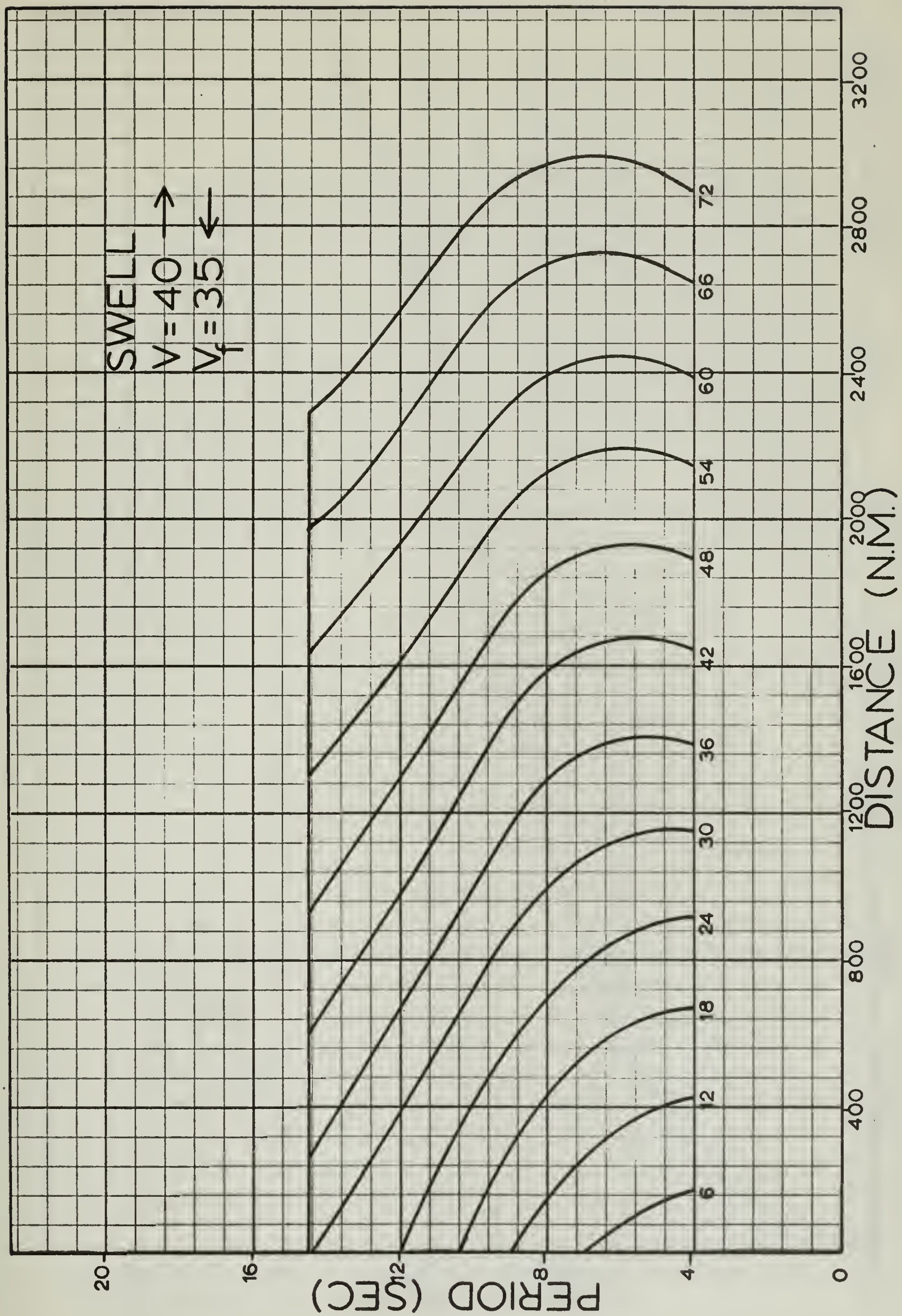

SWELL
V = 40
V_f = 25
DISTANCE (N.M.)
PERIOD (SEC)
0
4
8
12
16
20
300
600
900
1200
1500
1800
2100
2400
6
12
18
24
30
36
42
48
54
60
66
72

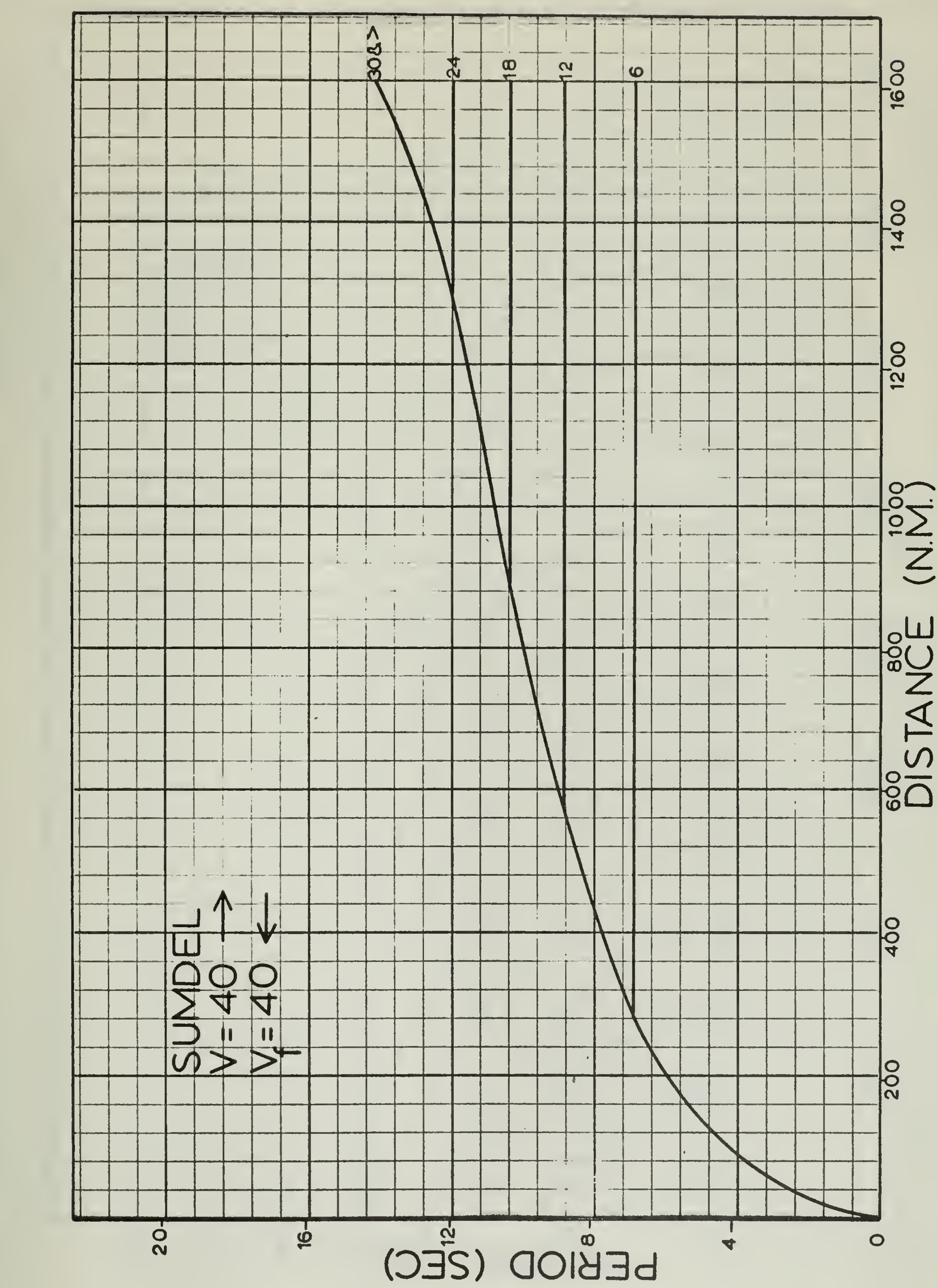


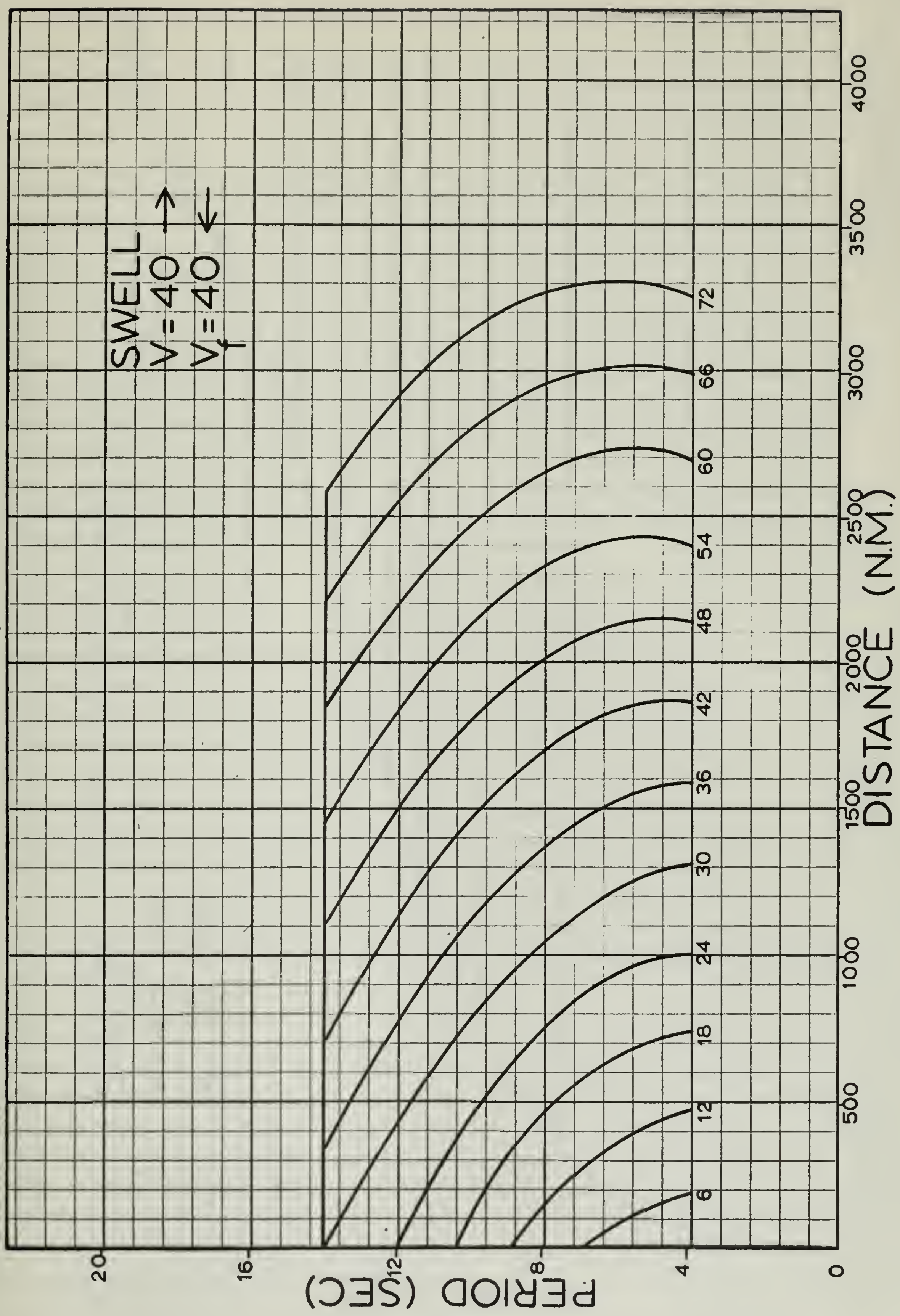
SUMDEL
V = 40 →
Vf = 30 ←
36 & >
30
24
18
12
6
0
4
8
12
16
20
PERIOD (SEC)
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)

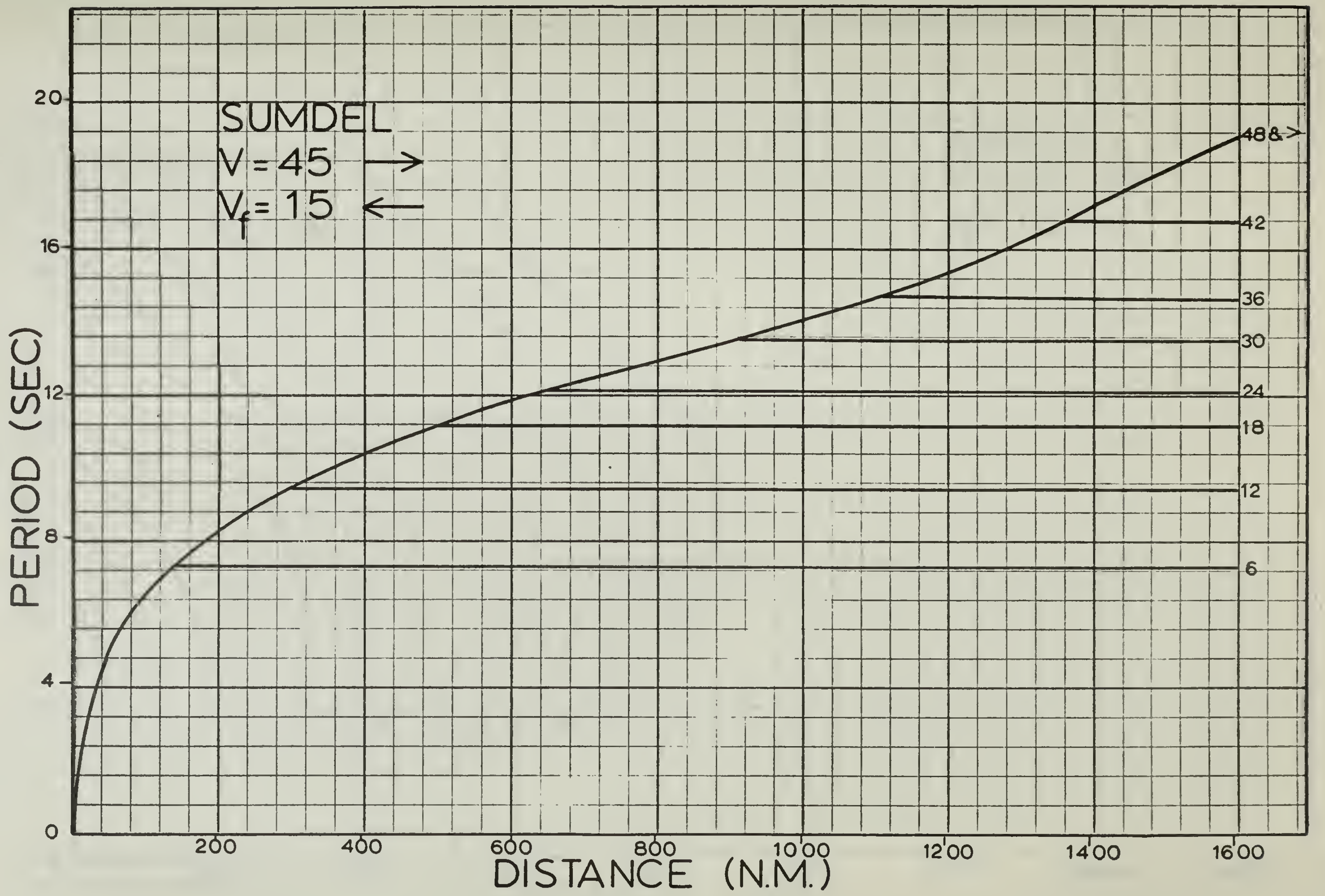

SWELL
V = 40
$V_f$ = 30
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
400
800
1200
1600
2000
2400
2800
3200
6
12
18
24
30
36
42
48
54
60
66
72


SUMDEL
V = 40 →
$V_f$ = 35 ←
30&>
24
18
12
6
0
4
8
12
16
20
PERIOD (SEC)
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)

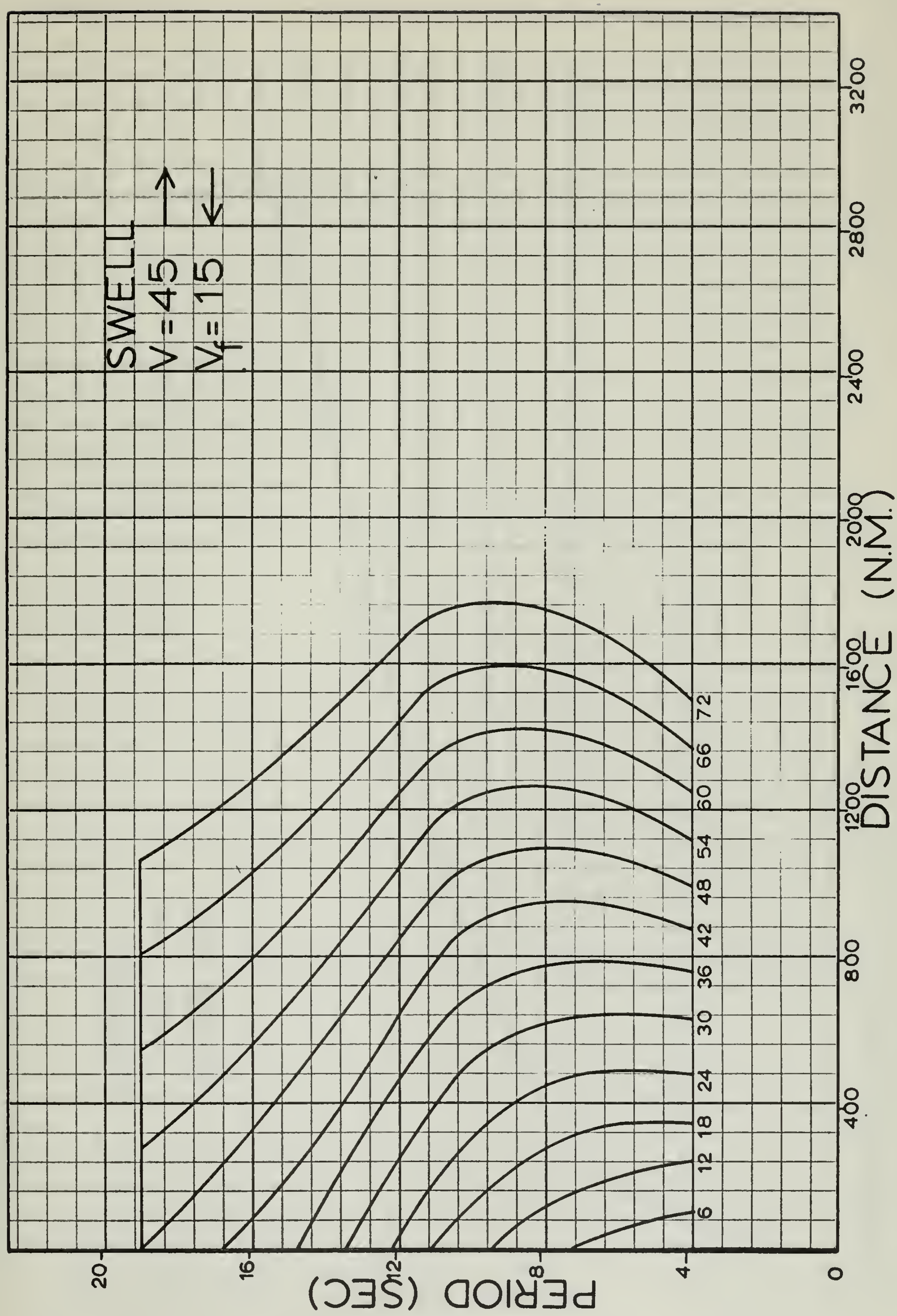

SWELL
V = 40 →
V_f = 35 ←
6
12
18
24
30
36
42
48
54
60
66
72
0
4
8
12
16
20
PERIOD (SEC)
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)


SUMDEL
V = 40 →
$V_f$ = 40 ←
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
6
12
18
24
30&>

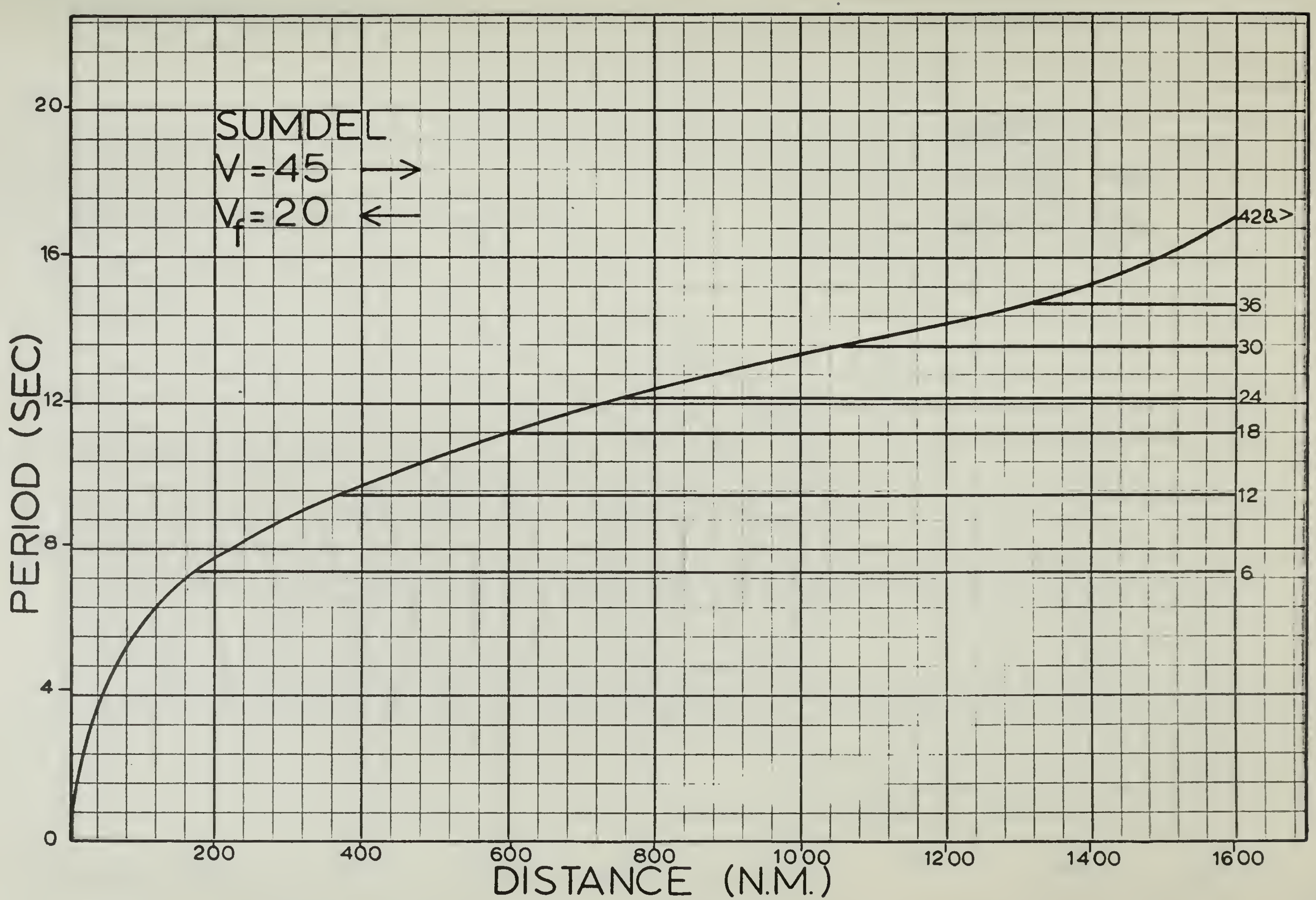

SWELL
V = 40 →
V_f = 40 ←
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
500
1000
1500
2000
2500
3000
3500
4000
6
12
18
24
30
36
42
48
54
60
66
72

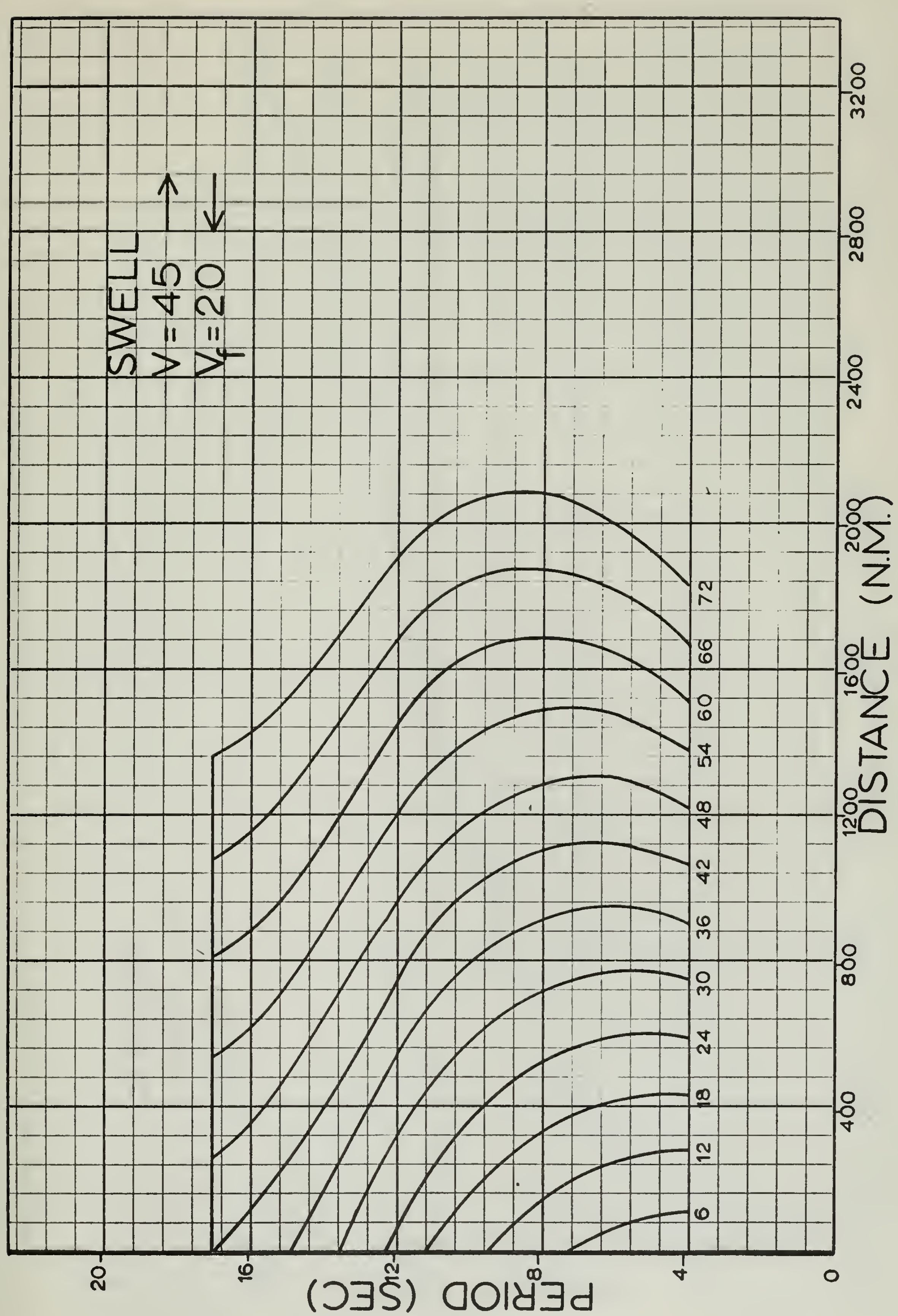


SUMDEL
V = 45
Vf = 15
48&>
42
36
30
24
18
12
6
20
16
12
8
4
0
PERIOD (SEC)
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)

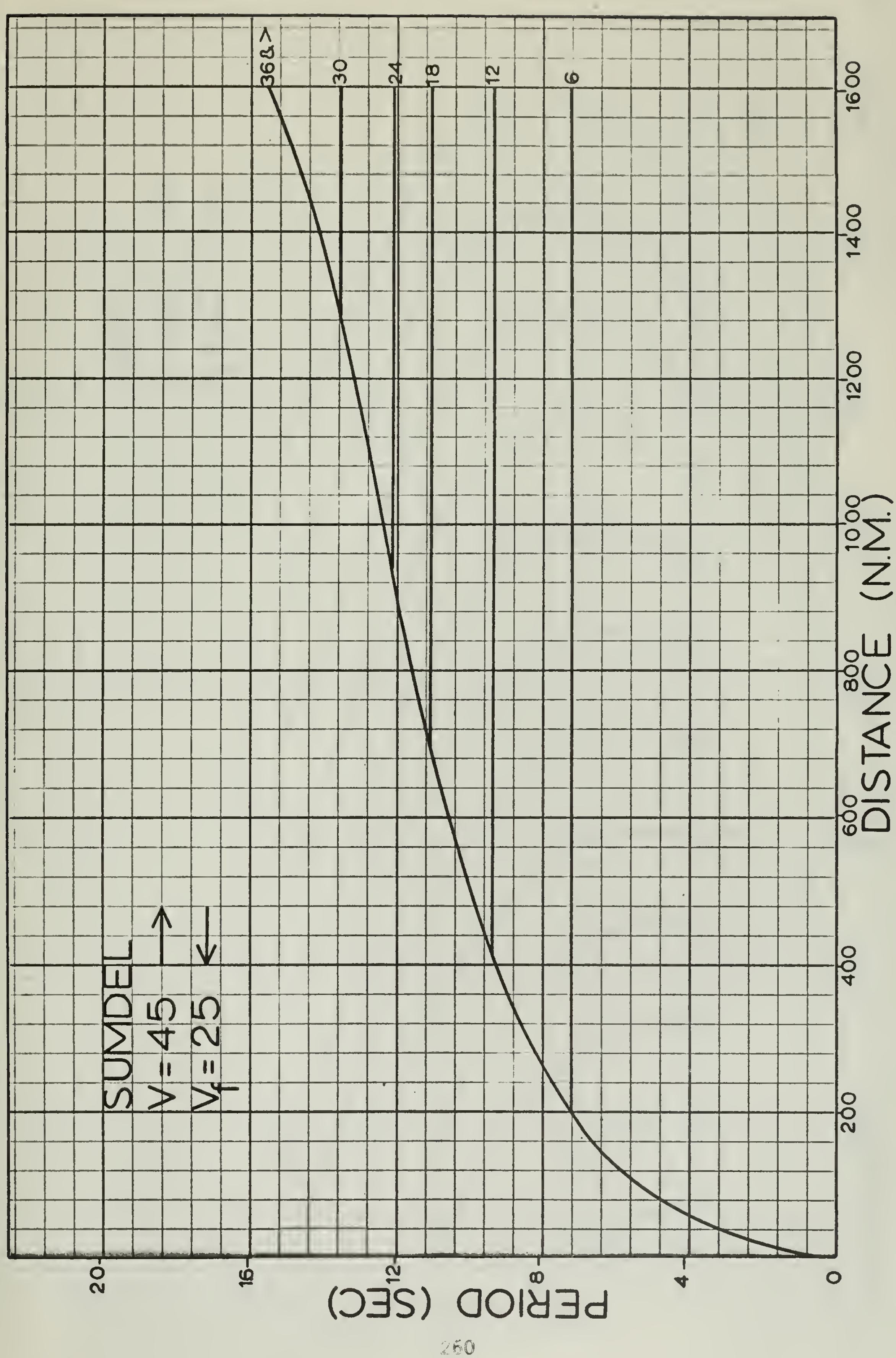


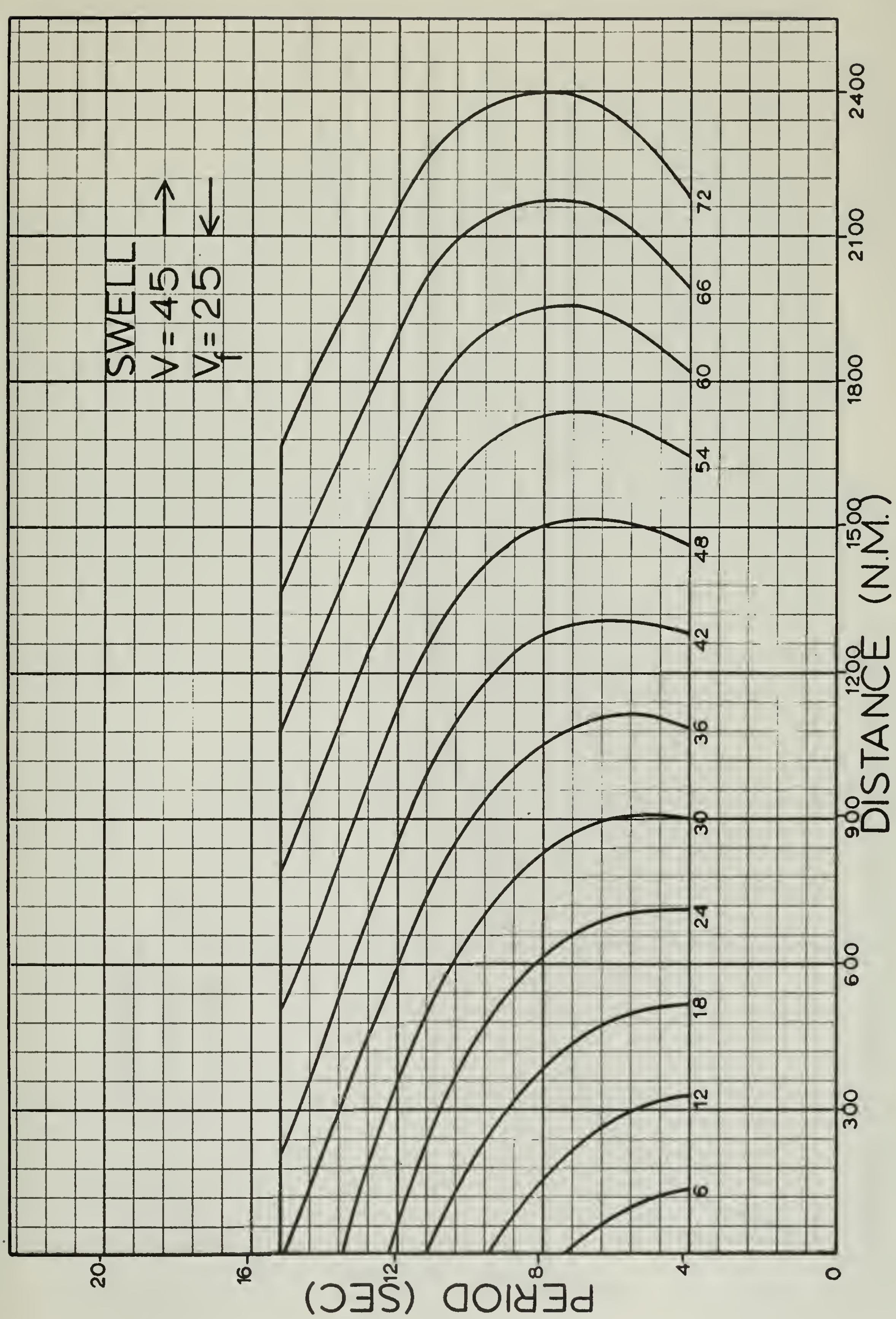
SWELL
V = 45
$V_f$ = 15
DISTANCE (N.M.)
PERIOD (SEC)
0
400
800
1200
1600
2000
2400
2800
3200
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72

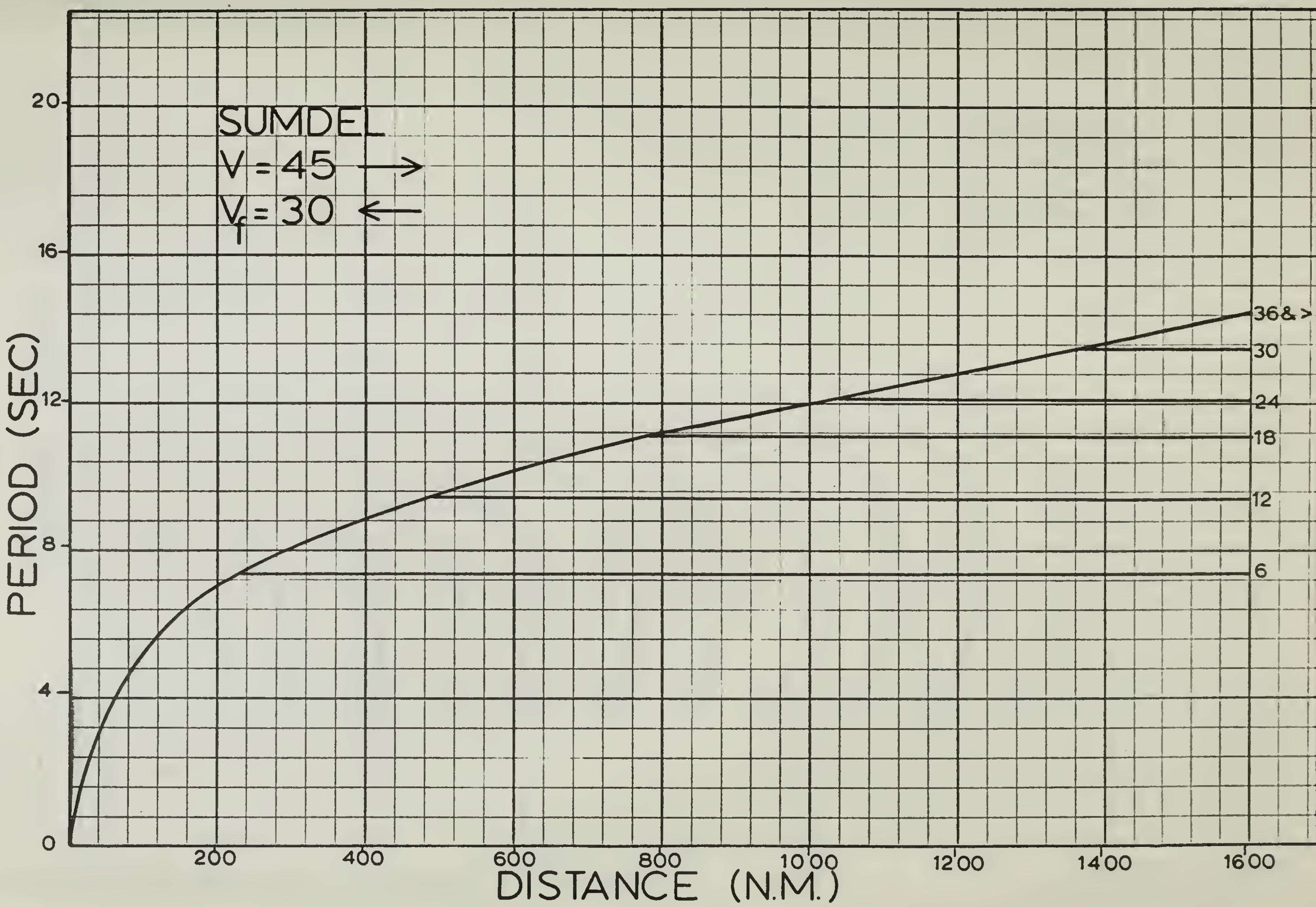

SUMDEL
V = 45
Vf = 20
42&>
36
30
24
18
12
6
20
16
12
8
4
0
PERIOD (SEC)
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)

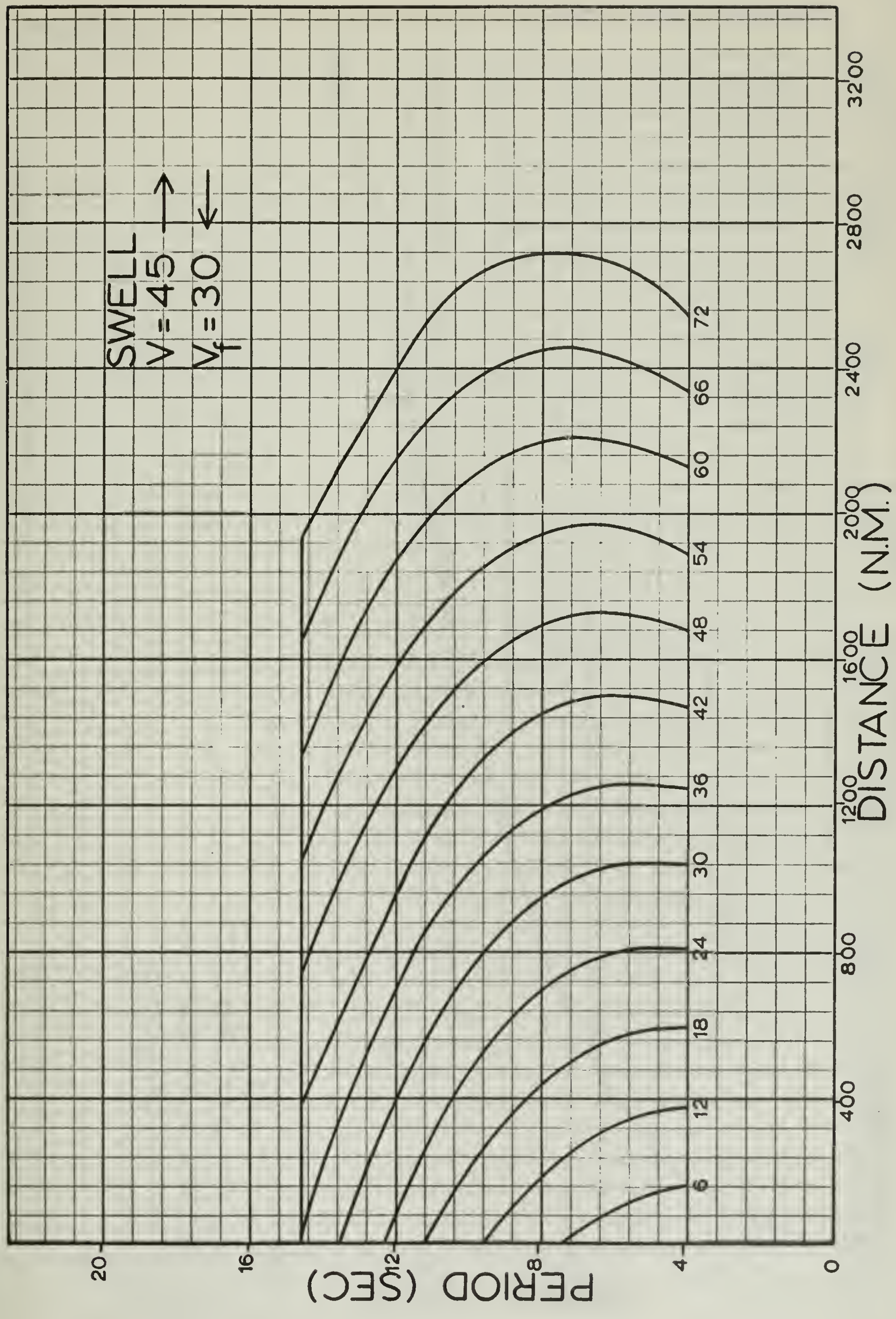


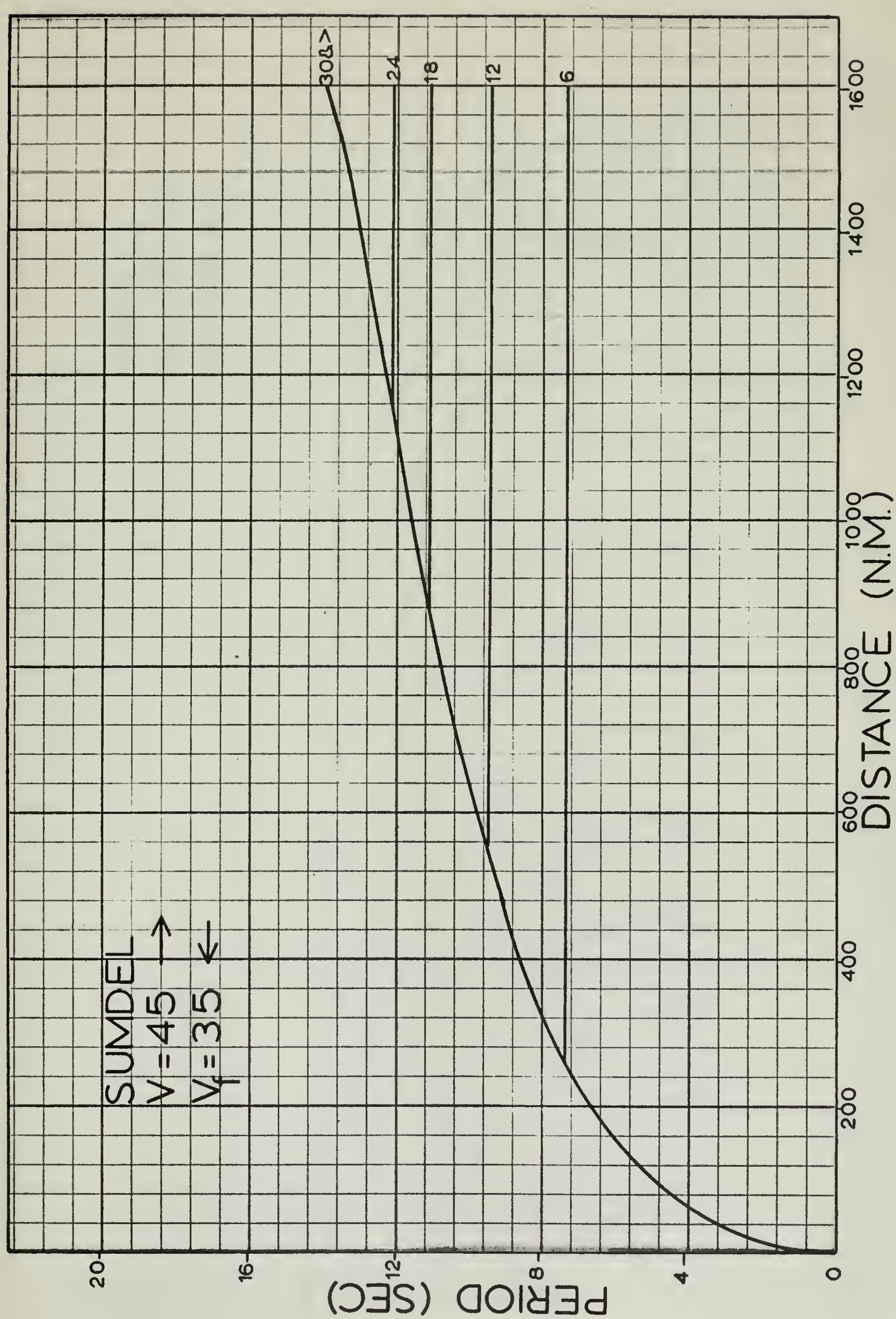
SWELL
V = 45
$V_f$ = 20
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
400
800
1200
1600
2000
2400
2800
3200
6
12
18
24
30
36
42
48
54
60
66
72

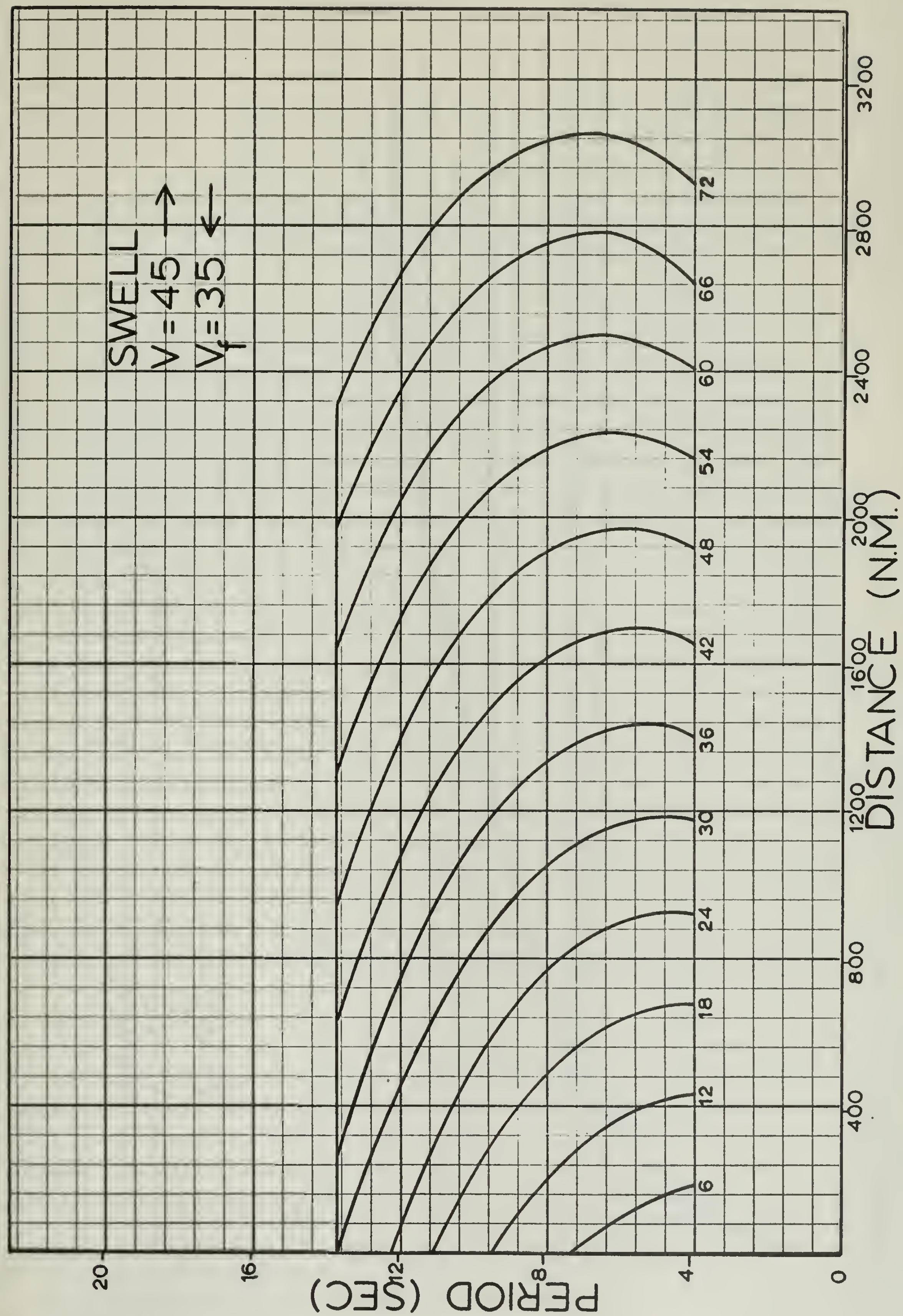

SUMDEL
V = 45
V_f = 25
36&>
30
24
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600

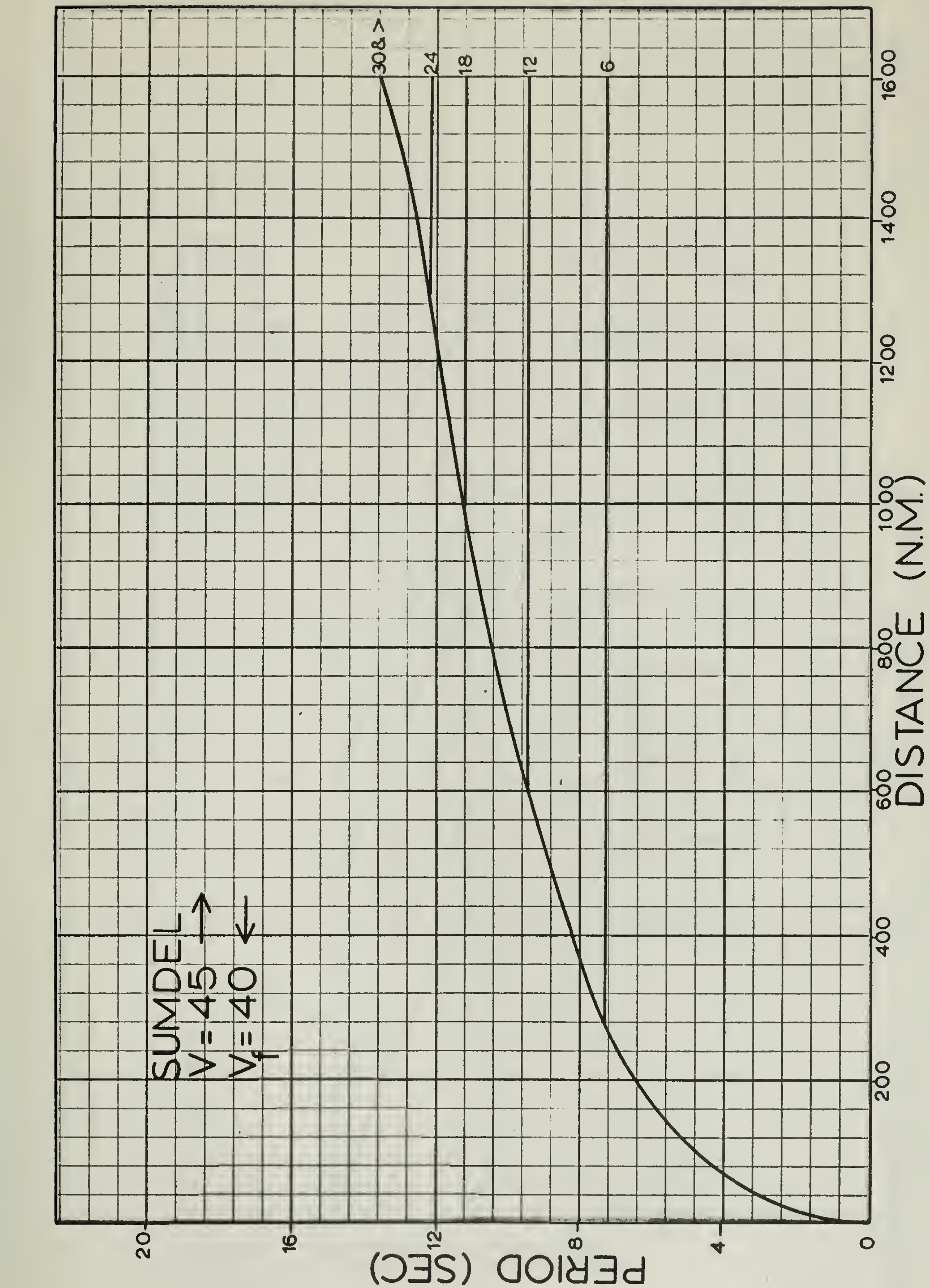

SWELL
V = 45
V_f = 25
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
300
600
900
1200
1500
1800
2100
2400
6
12
18
24
30
36
42
48
54
60
66
72

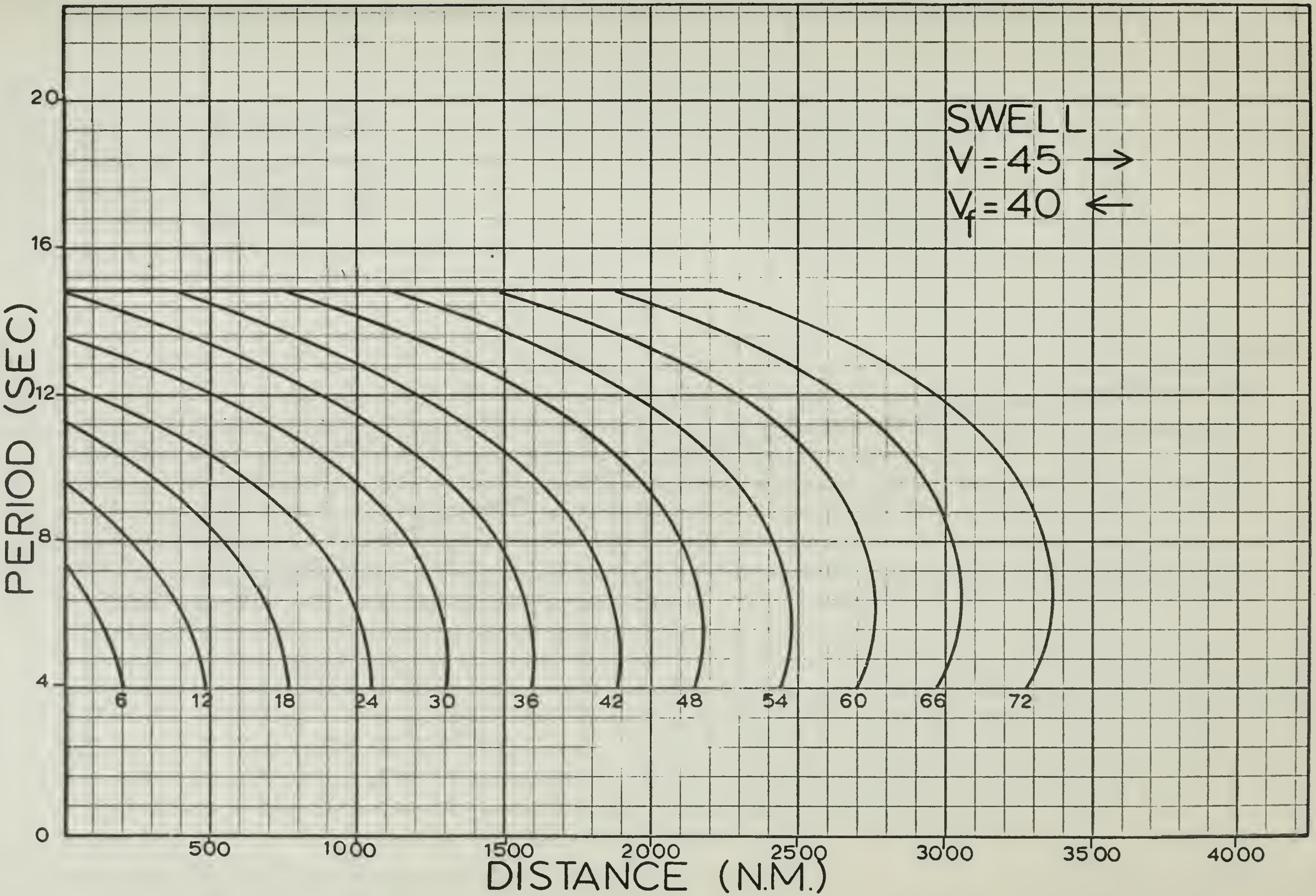

SUMDEL
V = 45
$V_f$ = 30
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
36 & >
30
24
18
12
6

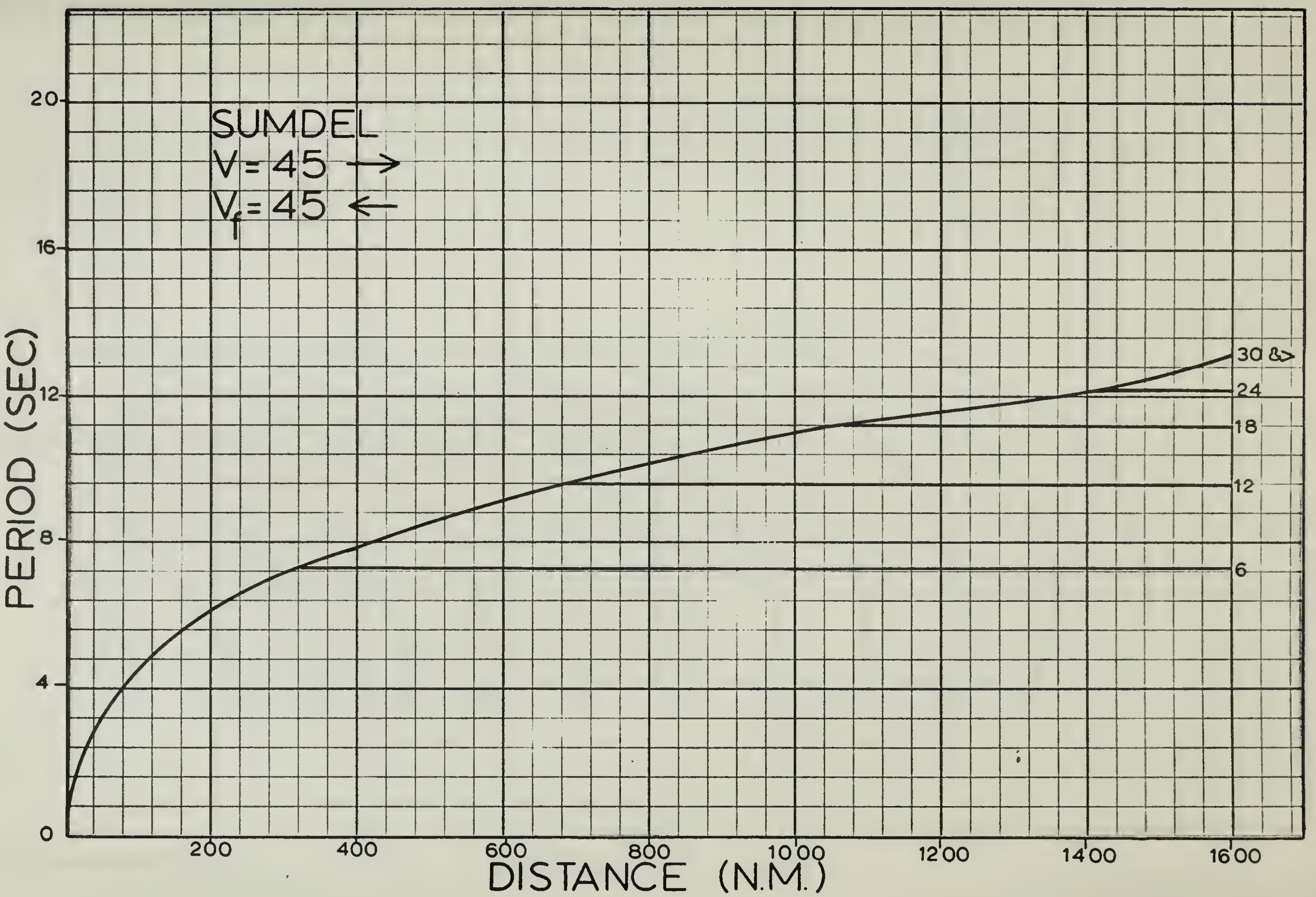

SWELL
V = 45
V_f = 30
DISTANCE (N.M.)
PERIOD (SEC)
0
4
8
12
16
20
400
800
1200
1600
2000
2400
2800
3200
6
12
18
24
30
36
42
48
54
60
66
72

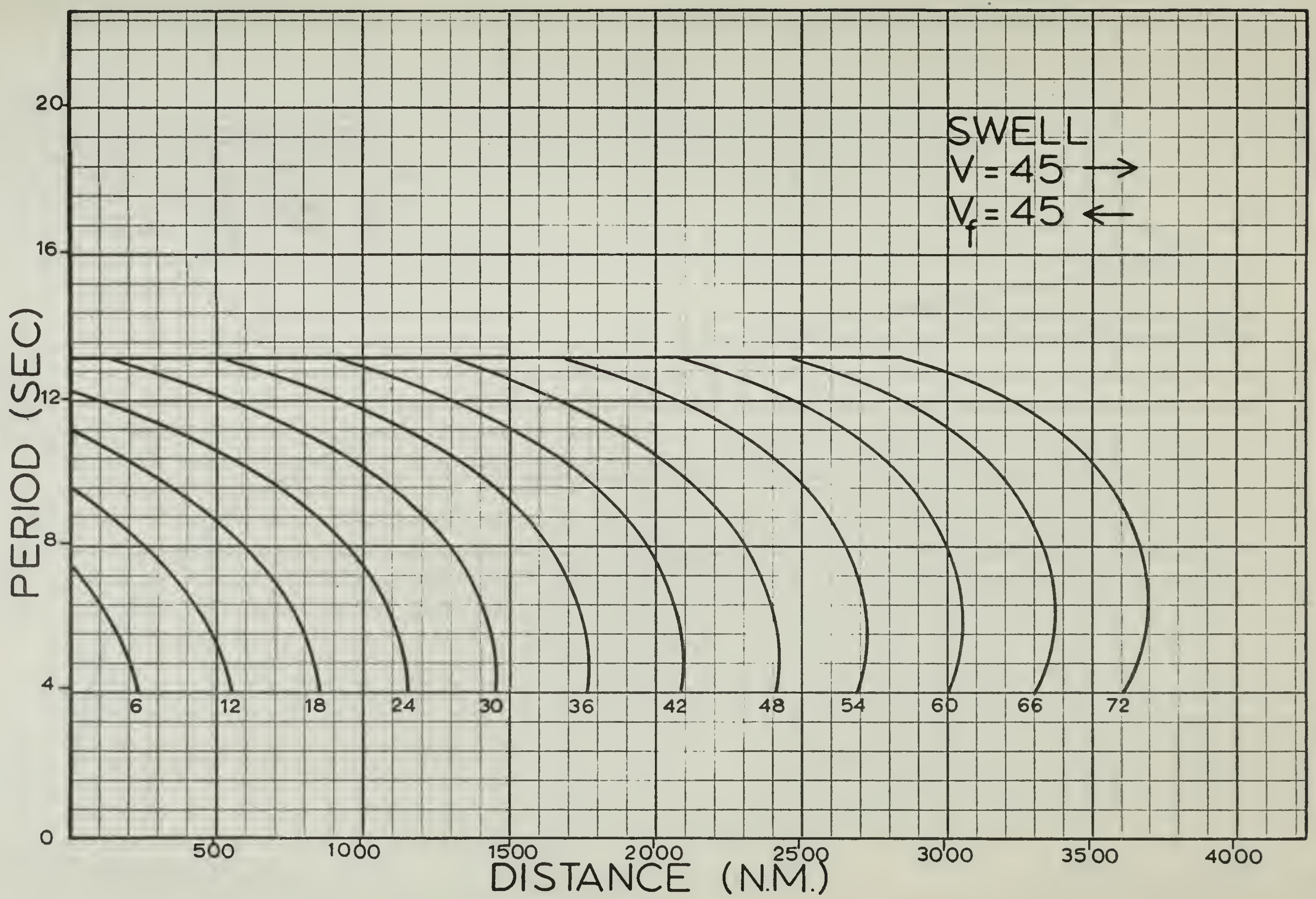

SUMDEL
V = 45 →
V_f = 35 ←
30&>
24
18
12
6
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600

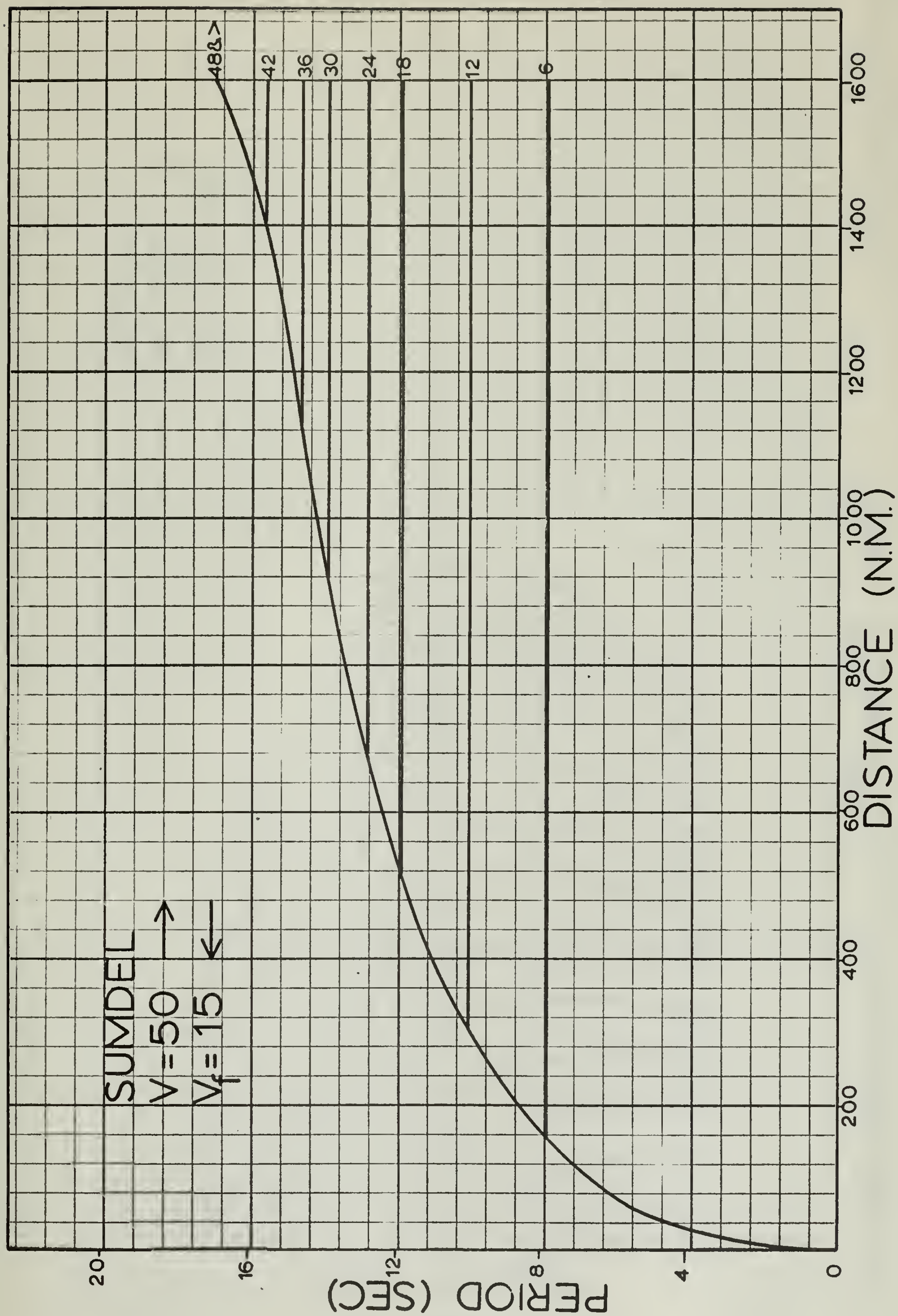

SWELL
V = 45 →
V_f = 35 ←
6
12
18
24
30
36
42
48
54
60
66
72
0
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)
0
4
8
12
16
20
PERIOD (SEC)


SUMDEL
V = 45 →
$V_f$ = 40 ←
30& >
24
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600


SWELL
V = 45
$V_f$ = 40
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
500
1000
1500
2000
2500
3000
3500
4000
6
12
18
24
30
36
42
48
54
60
66
72


SUMDEL
V = 45 →
V_f = 45 ←
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
30 &>
24
18
12
6


SWELL
V = 45
$V_f$ = 45
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
500
1000
1500
2000
2500
3000
3500
4000
6
12
18
24
30
36
42
48
54
60
66
72


SUMDEL
V = 50
V_f = 15
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
200
400
600
800
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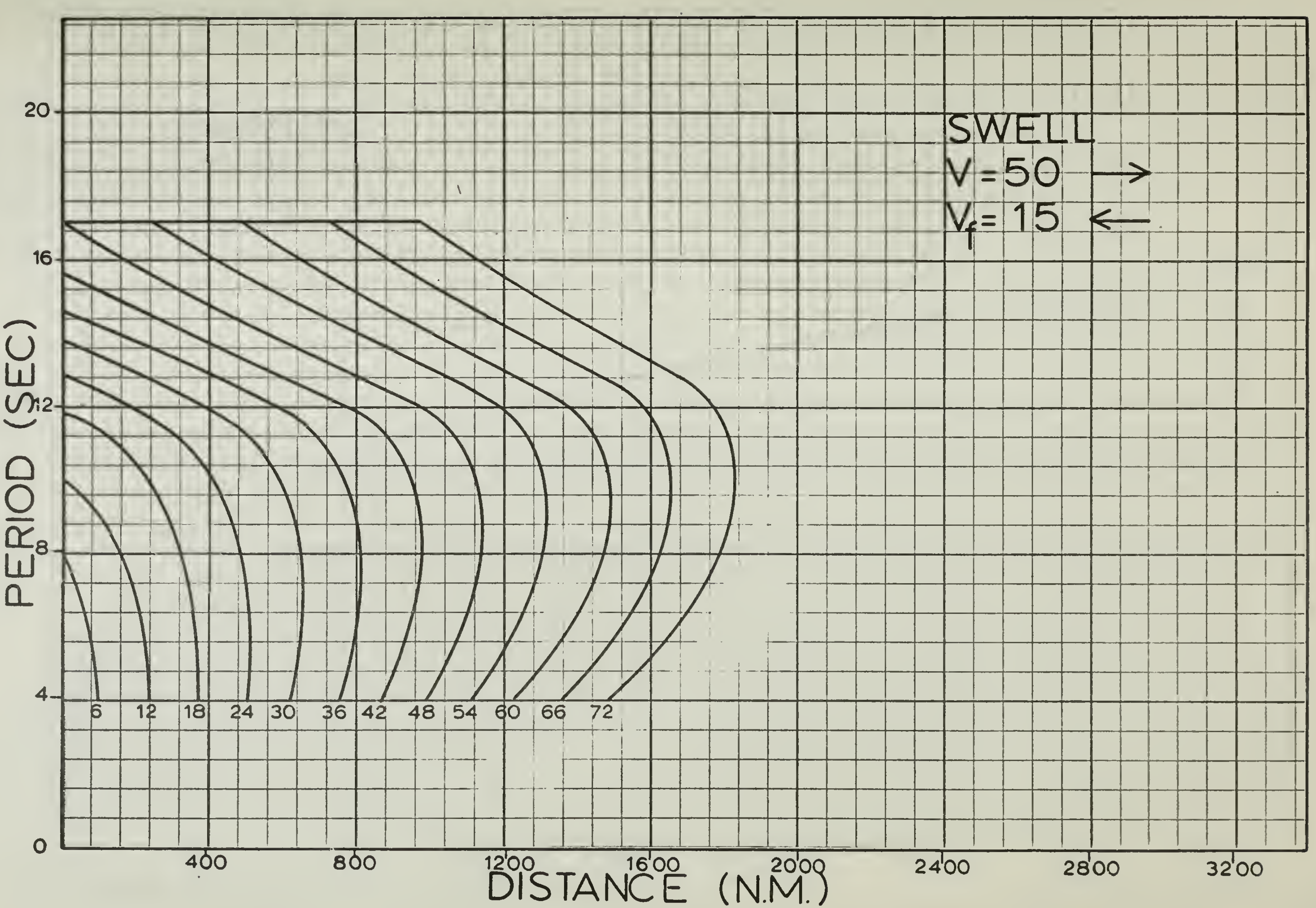
1400
1600
6
12
18
24
30
36
42
48&>



SWELL
V = 50
$V_f$ = 15
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
400
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1200
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2400
2800
3200
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18
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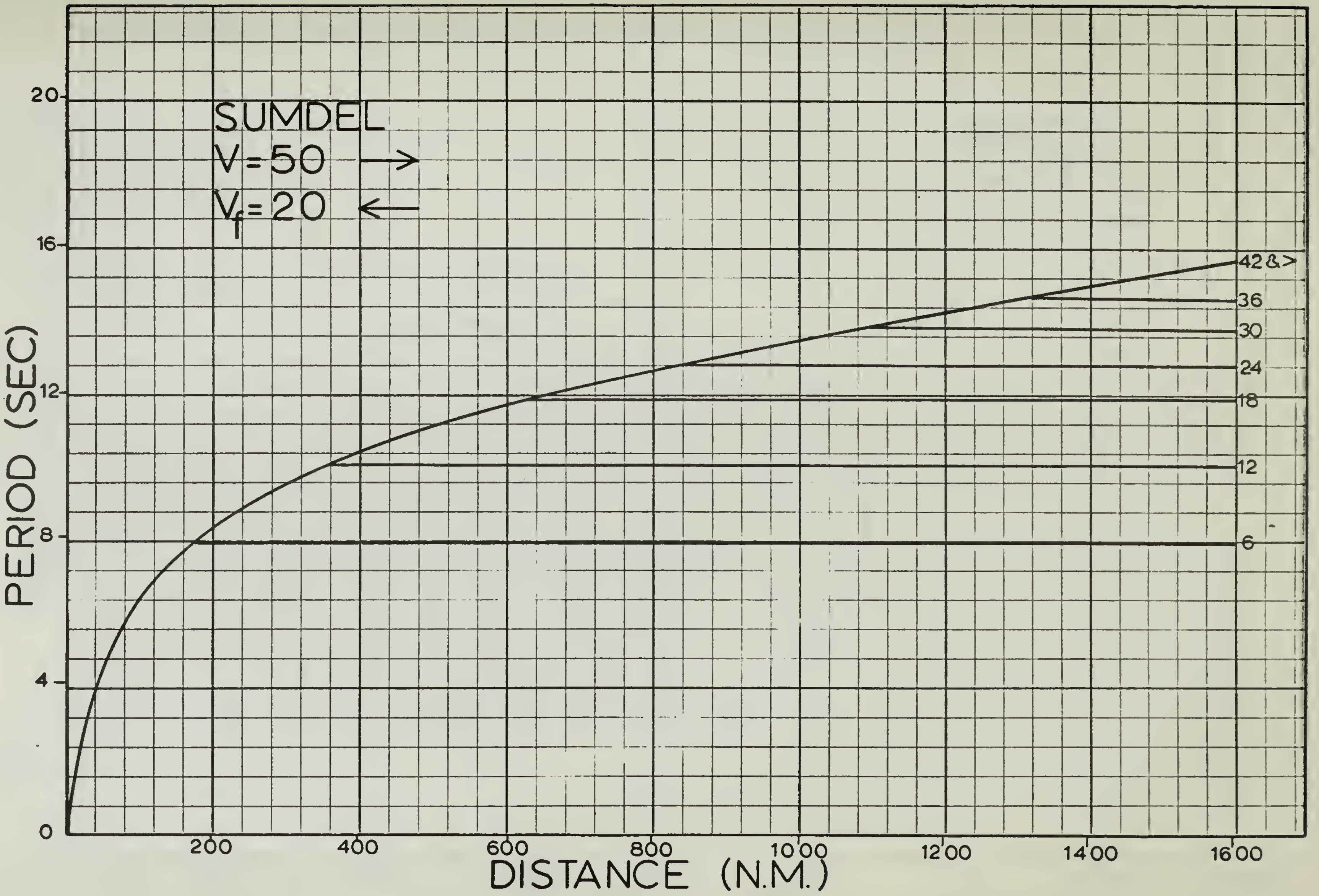
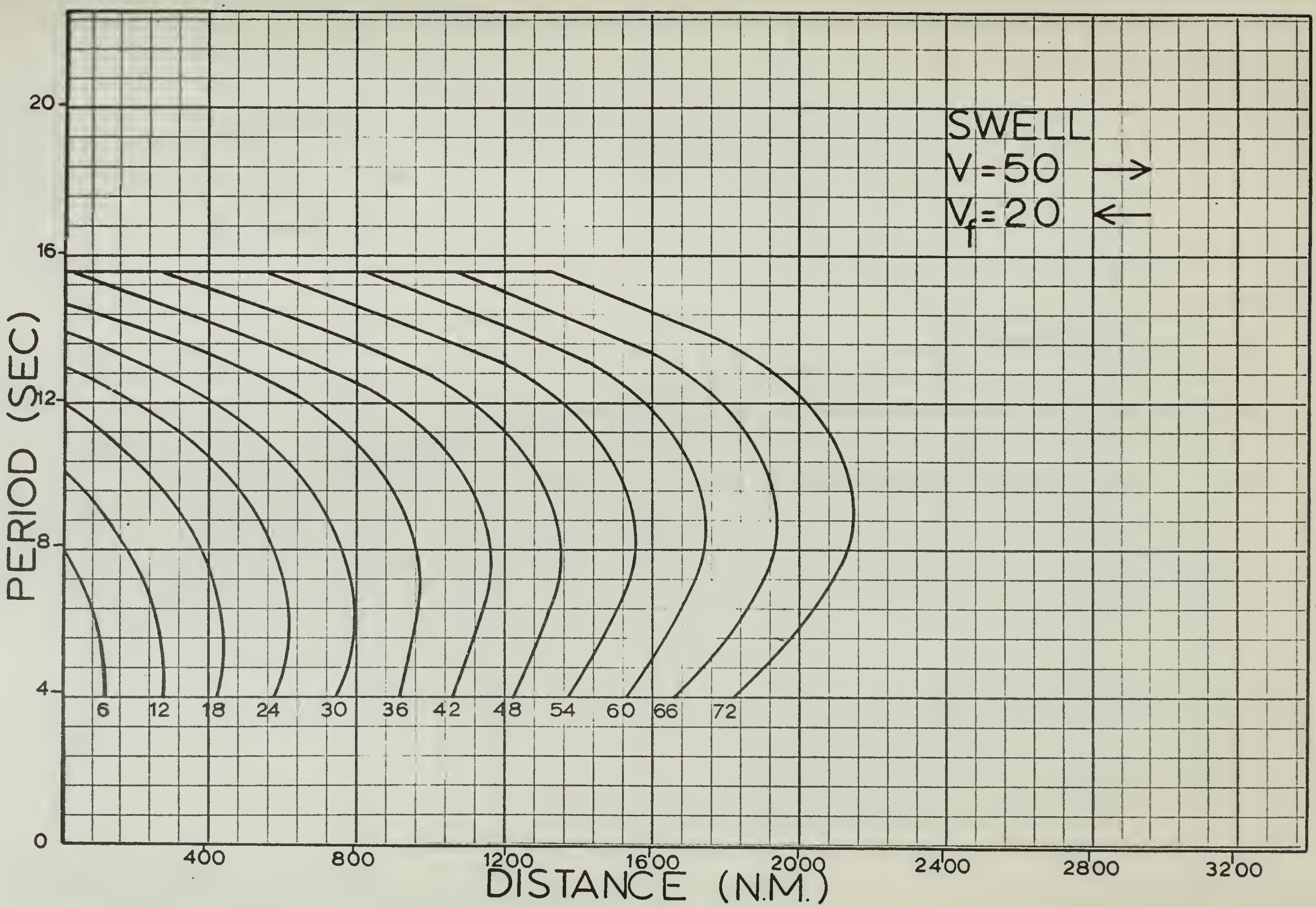
48
54
60
66
72


SUMDEL
V = 50
V_f = 20
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
6
12
18
24
30
36
42 & >



SWELL
V=50
Vf=20
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
400
800
1200
1600
2000
2400
2800
3200
6
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18
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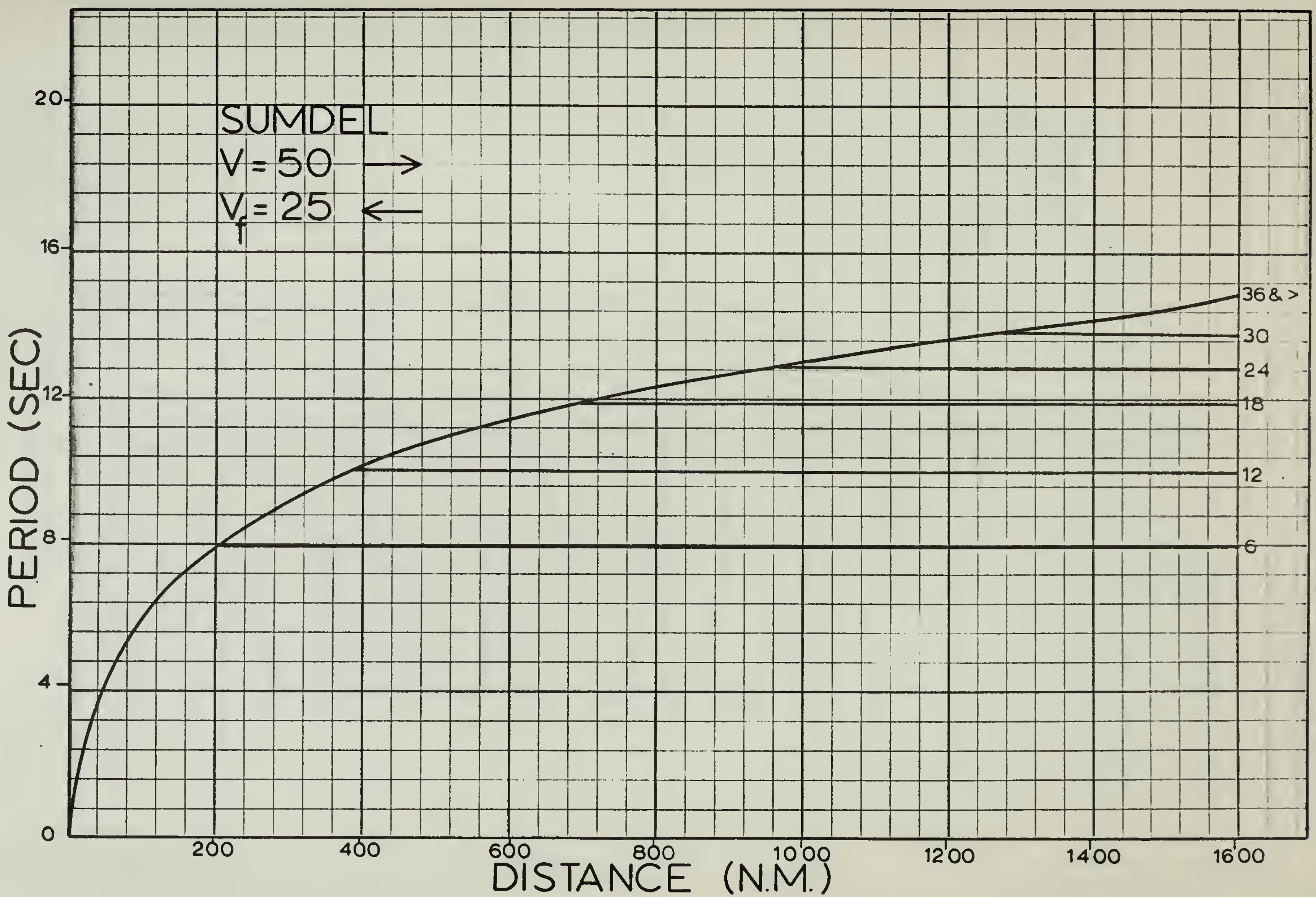
48
54
60
66
72


SUMDEL
V = 50
$V_f$ = 25
PERIOD (SEC)
DISTANCE (N.M.)
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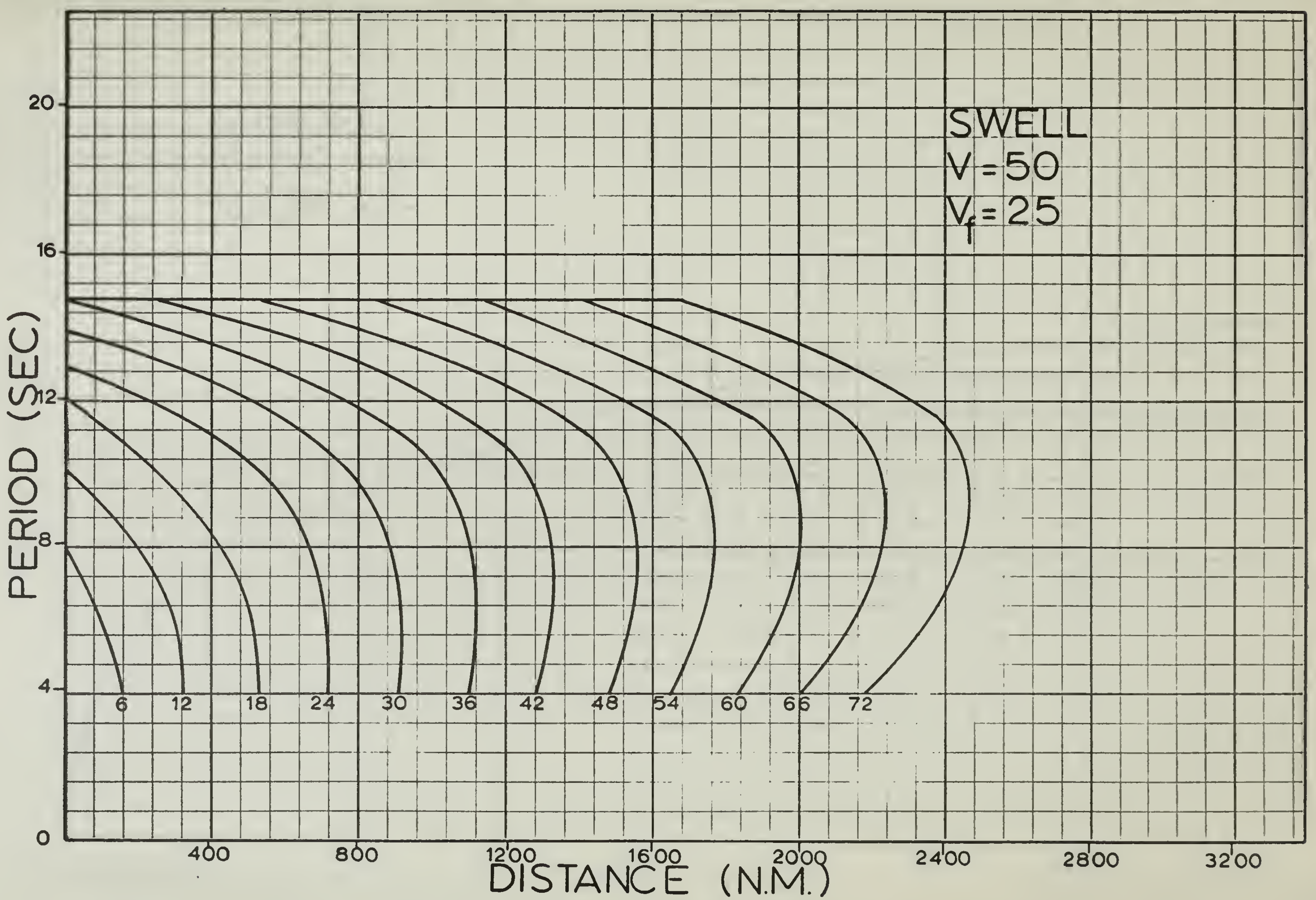
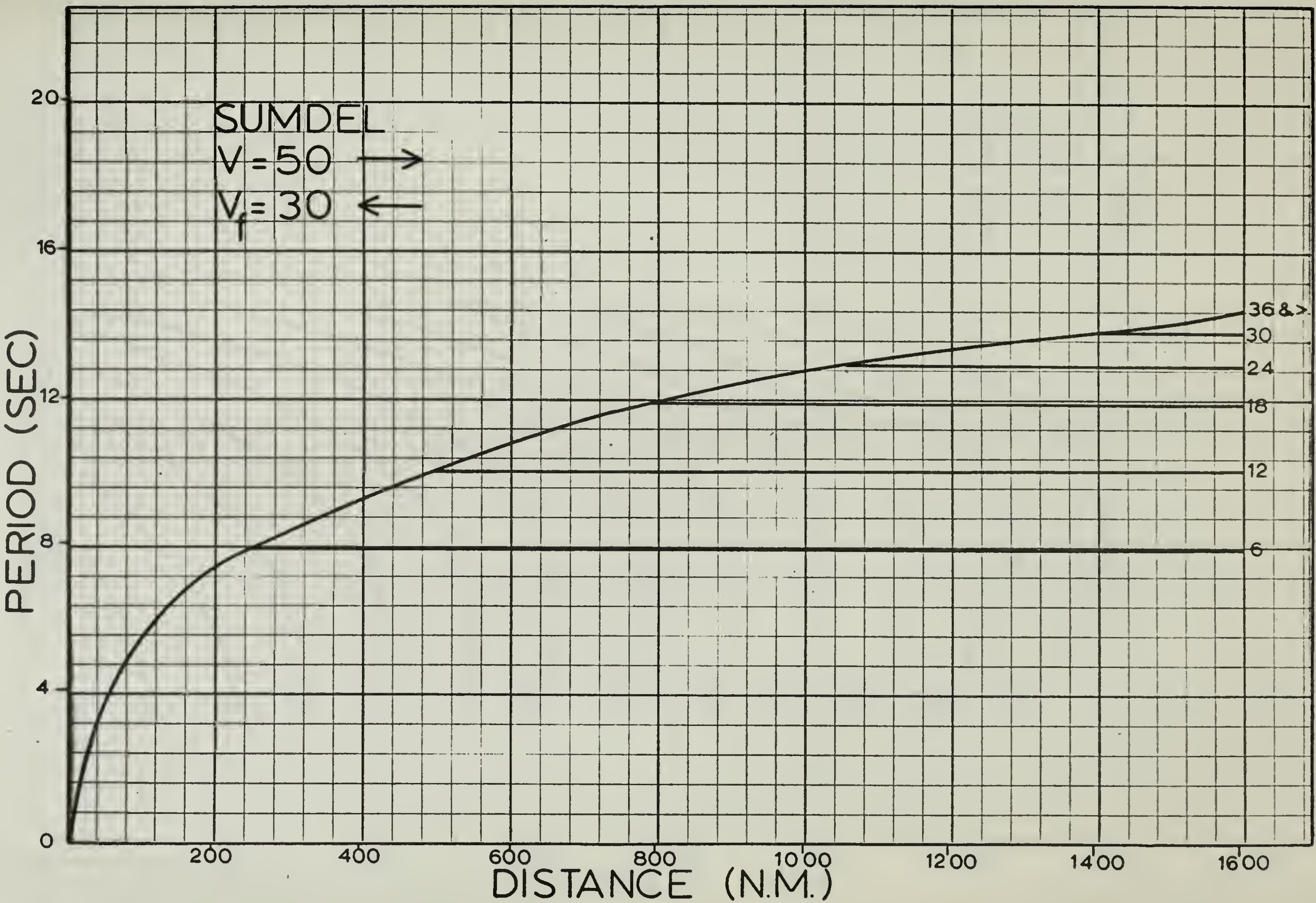
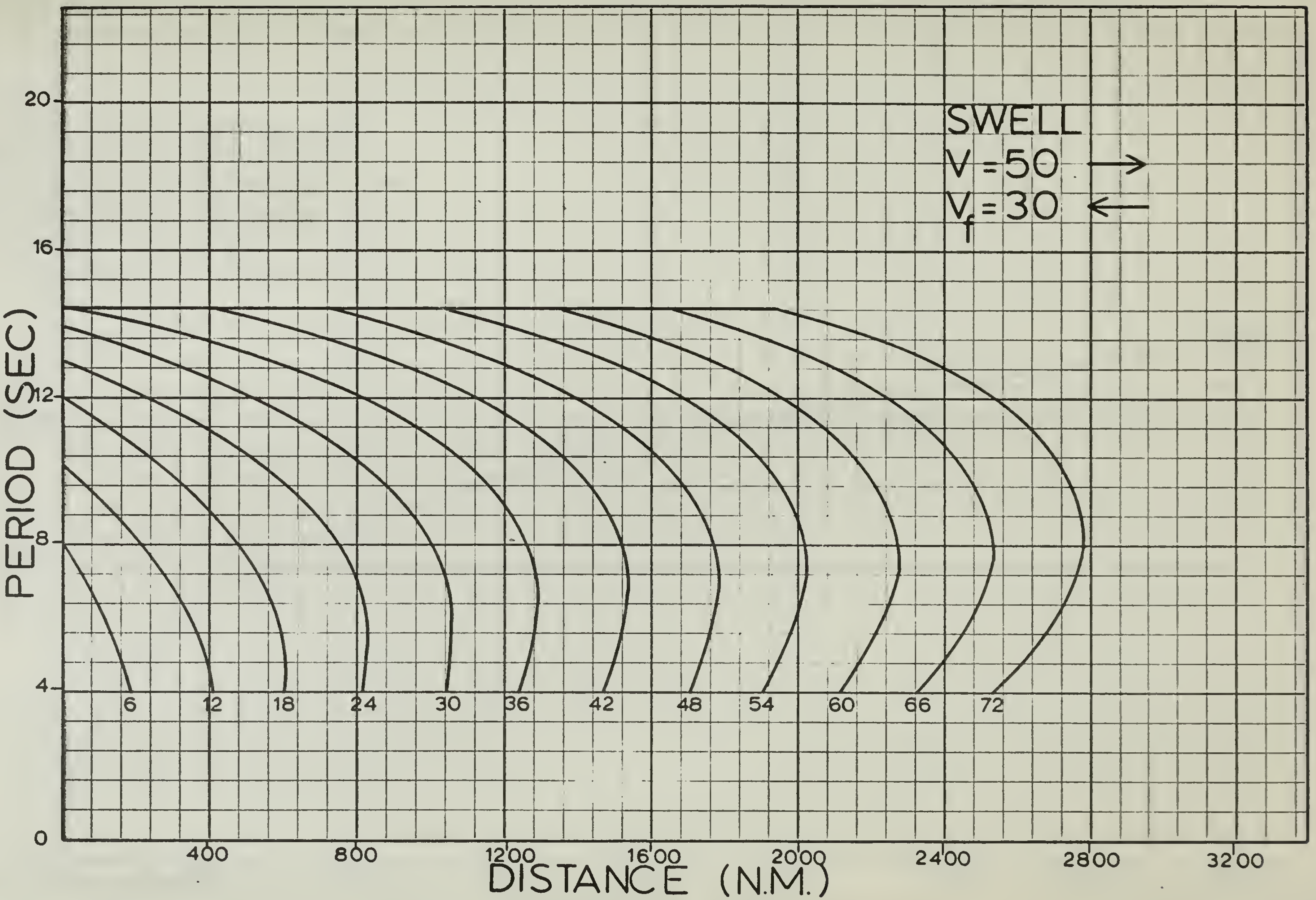
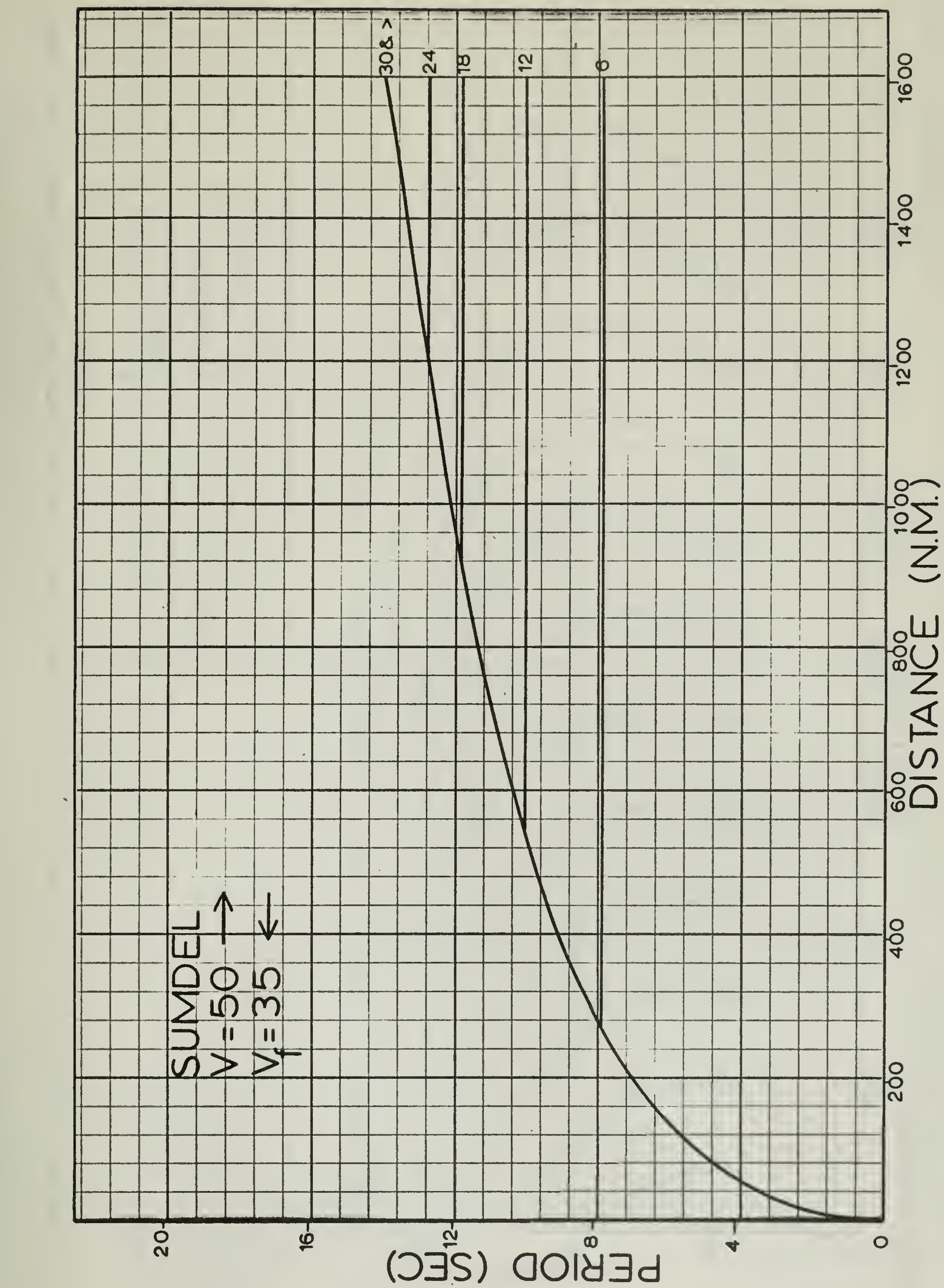
8
12
16
20
200
400
600
800
1000
1200
1400
1600
36 & >
30
24
18
12
6

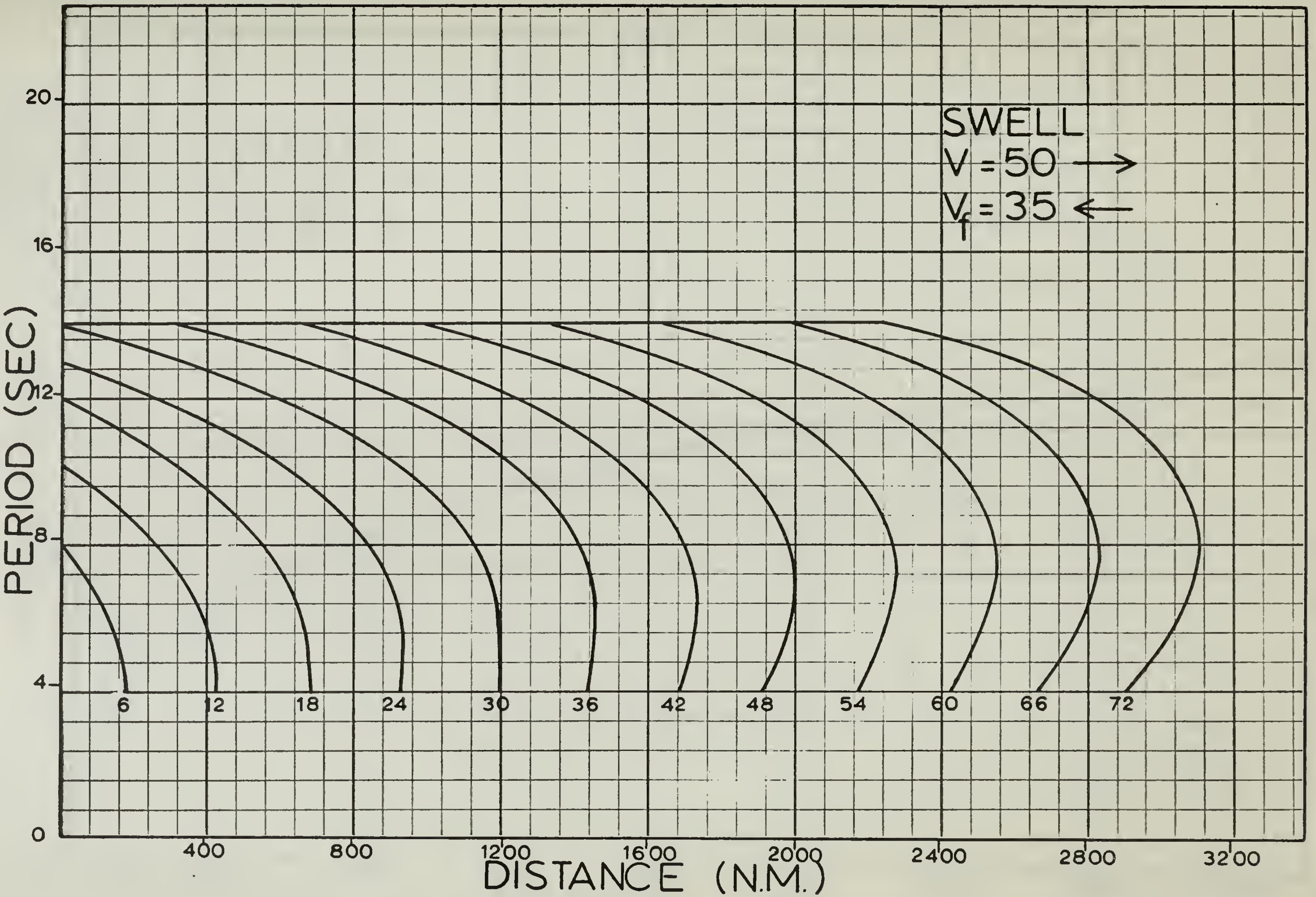

SWELL
V = 50
$V_f$ = 25
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
400
800
1200
1600
2000
2400
2800
3200
6
12
18
24
30
36
42
48
54
60
66
72

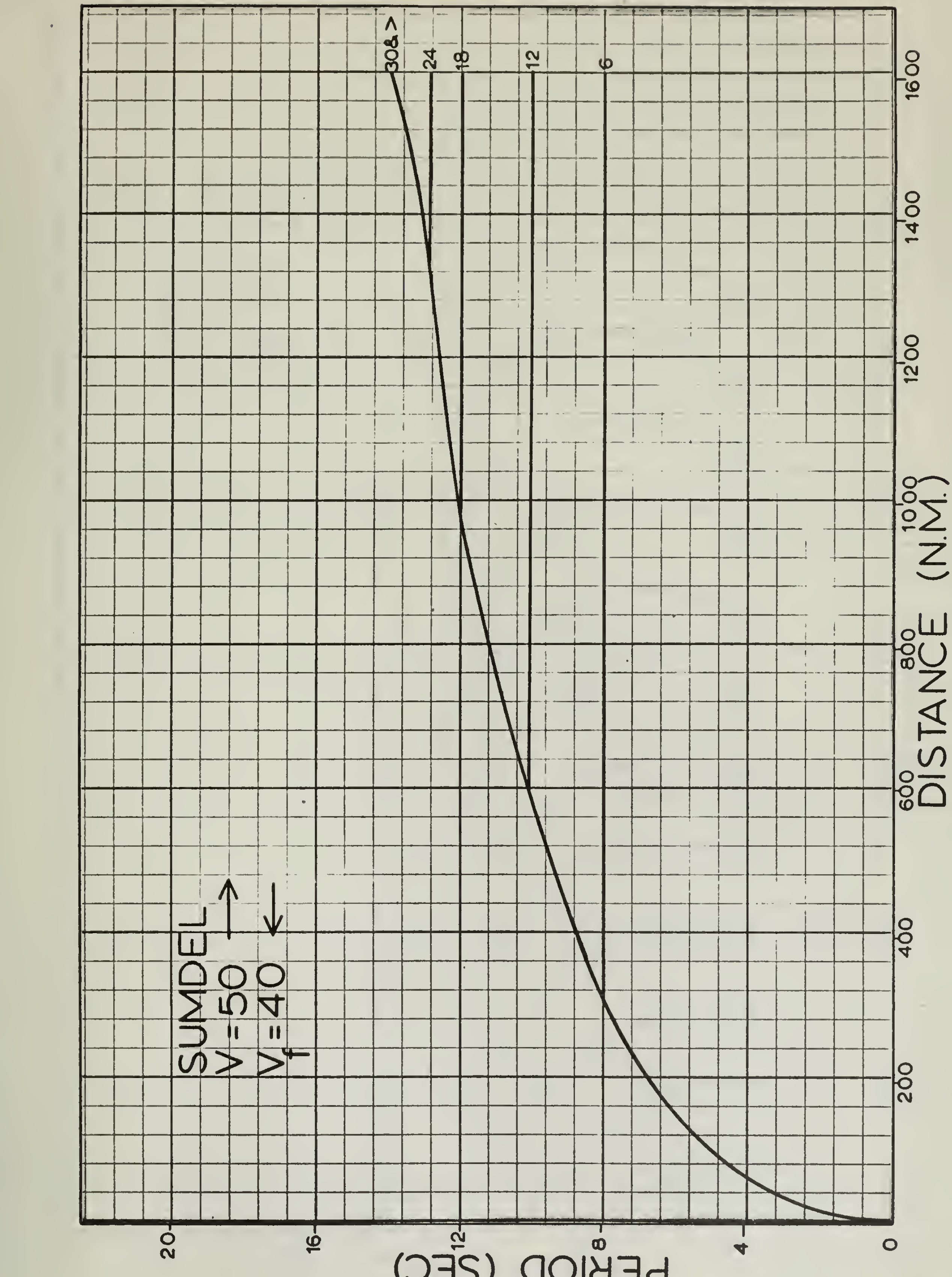

SUMDEL
V = 50
$V_f$ = 30
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
36 & >
30
24
18
12
6


SWELL
V = 50
$V_f$ = 30
PERIOD (SEC)
20
16
12
8
4
0
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)
6
12
18
24
30
36
42
48
54
60
66
72

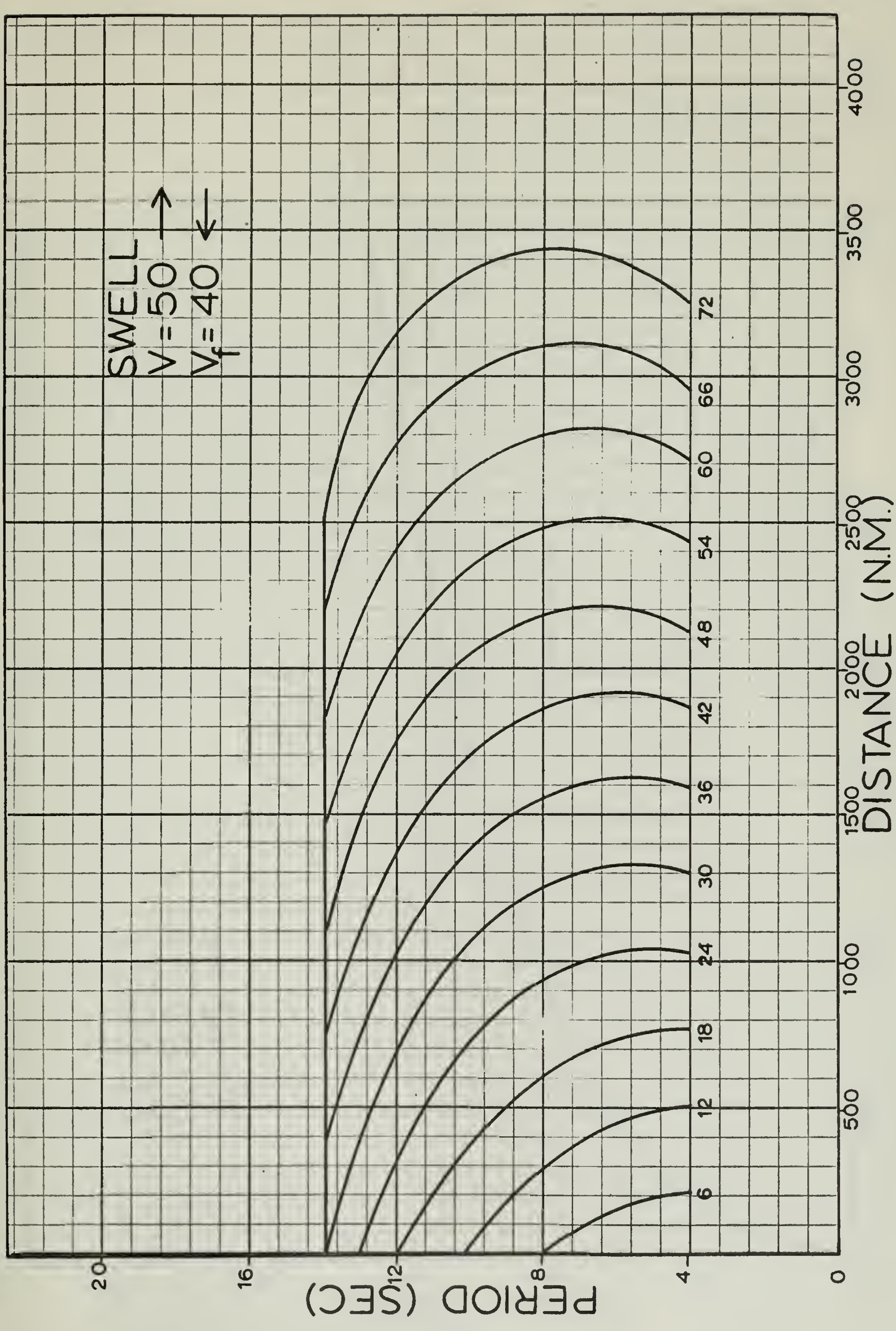


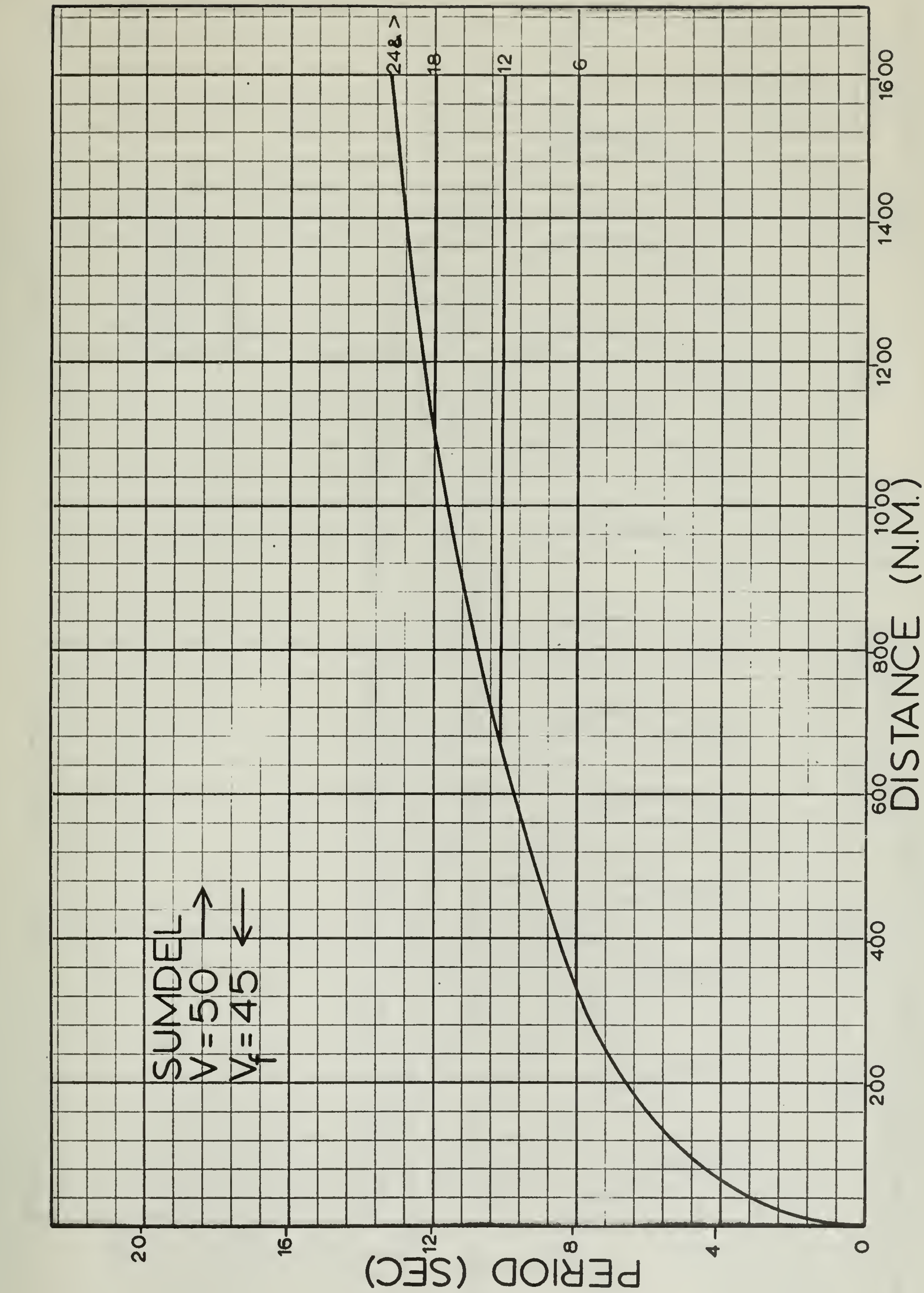
SUMDEL
V = 50 →
V_f = 35 ←
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
6
12
18
24
30 & >

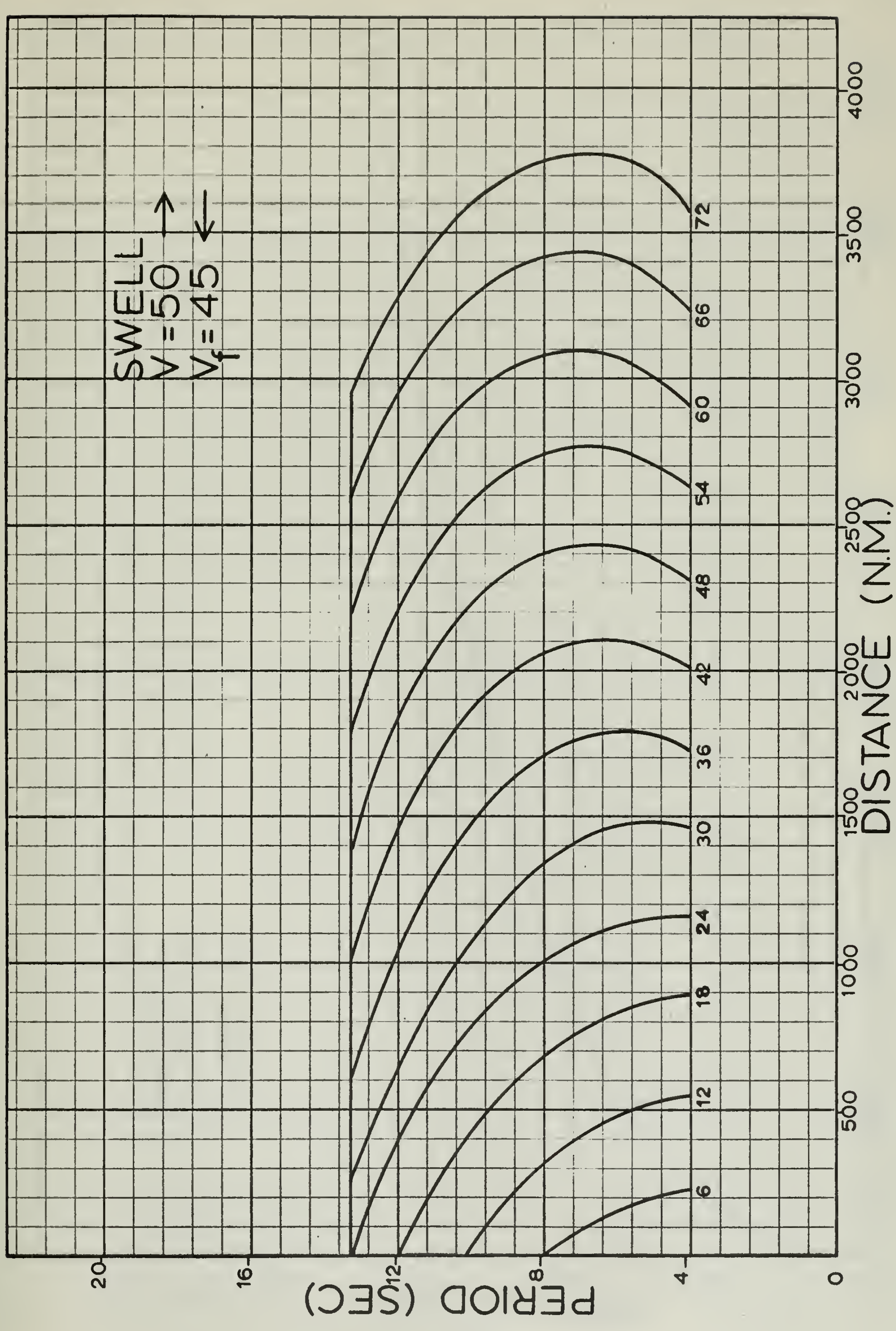

SWELL
V = 50 →
$V_f$ = 35 ←
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
400
800
1200
1600
2000
2400
2800
3200
6
12
18
24
30
36
42
48
54
60
66
72



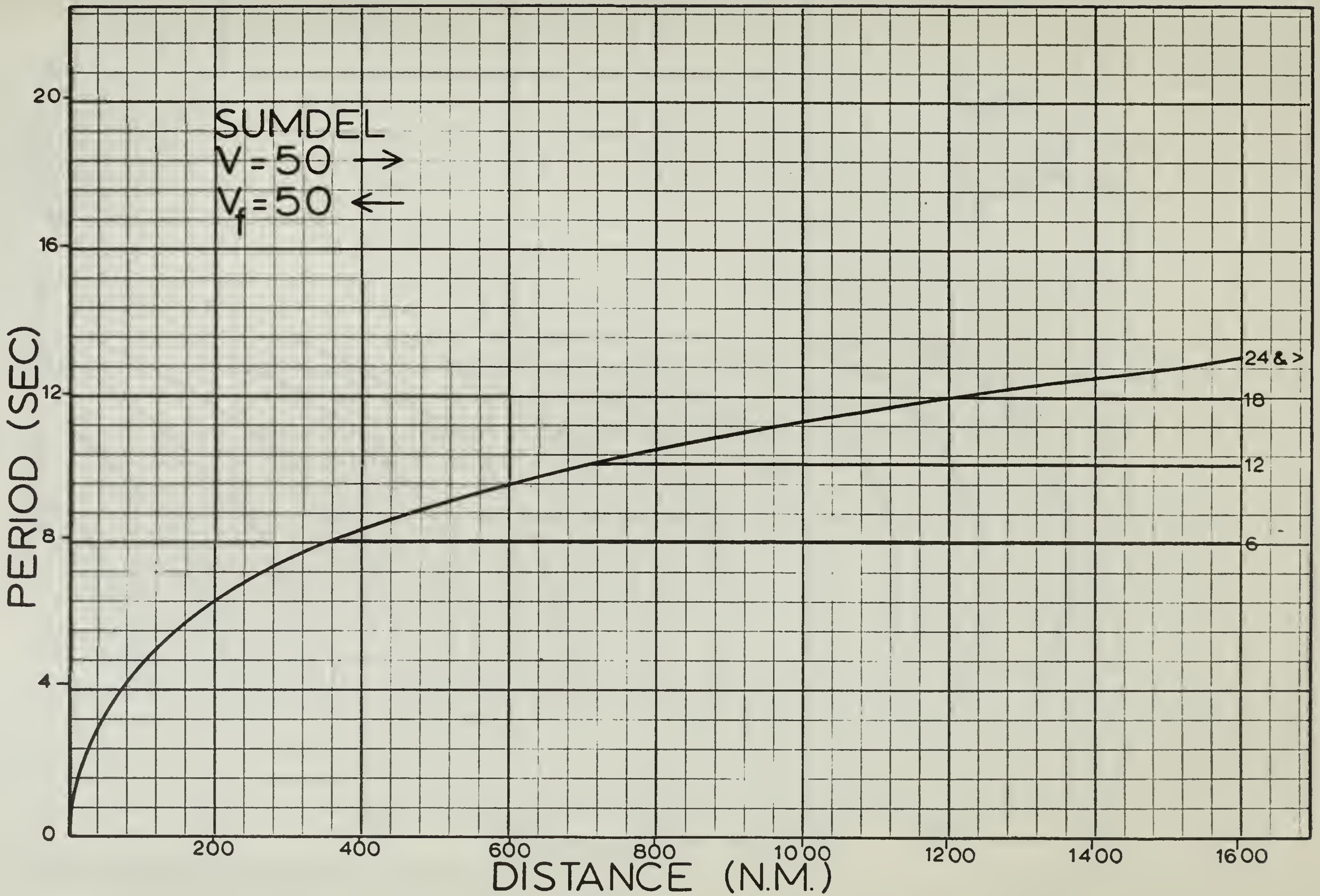
SUMDEL
V = 50 →
V_f = 40 ←
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
30& >
24
18
12
6


SWELL
V = 50
V_f = 40
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
500
1000
1500
2000
2500
3000
3500
4000
6
12
18
24
30
36
42
48
54
60
66
72

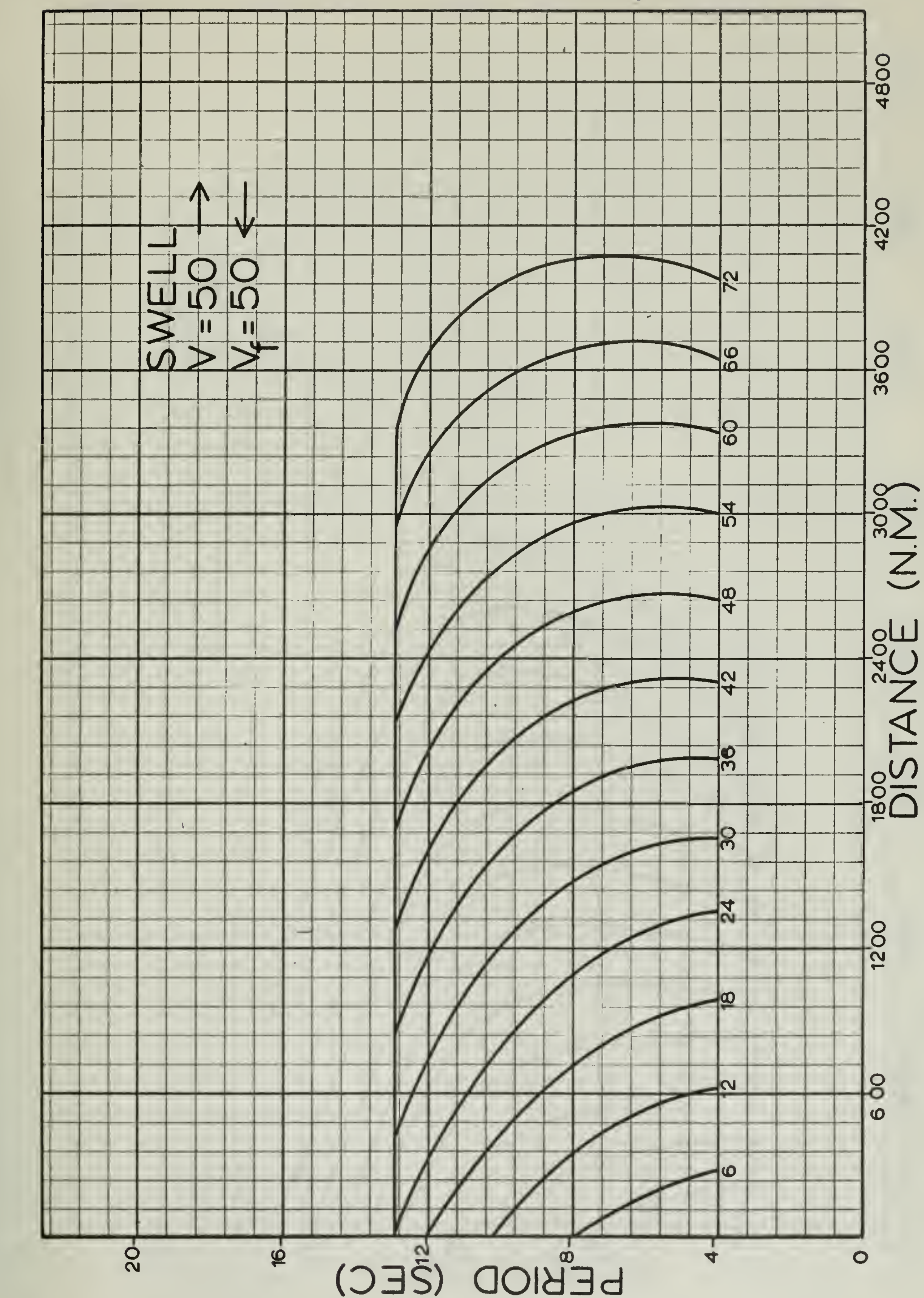

SUMDEL
V = 50
V_f = 45
24 & >
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600

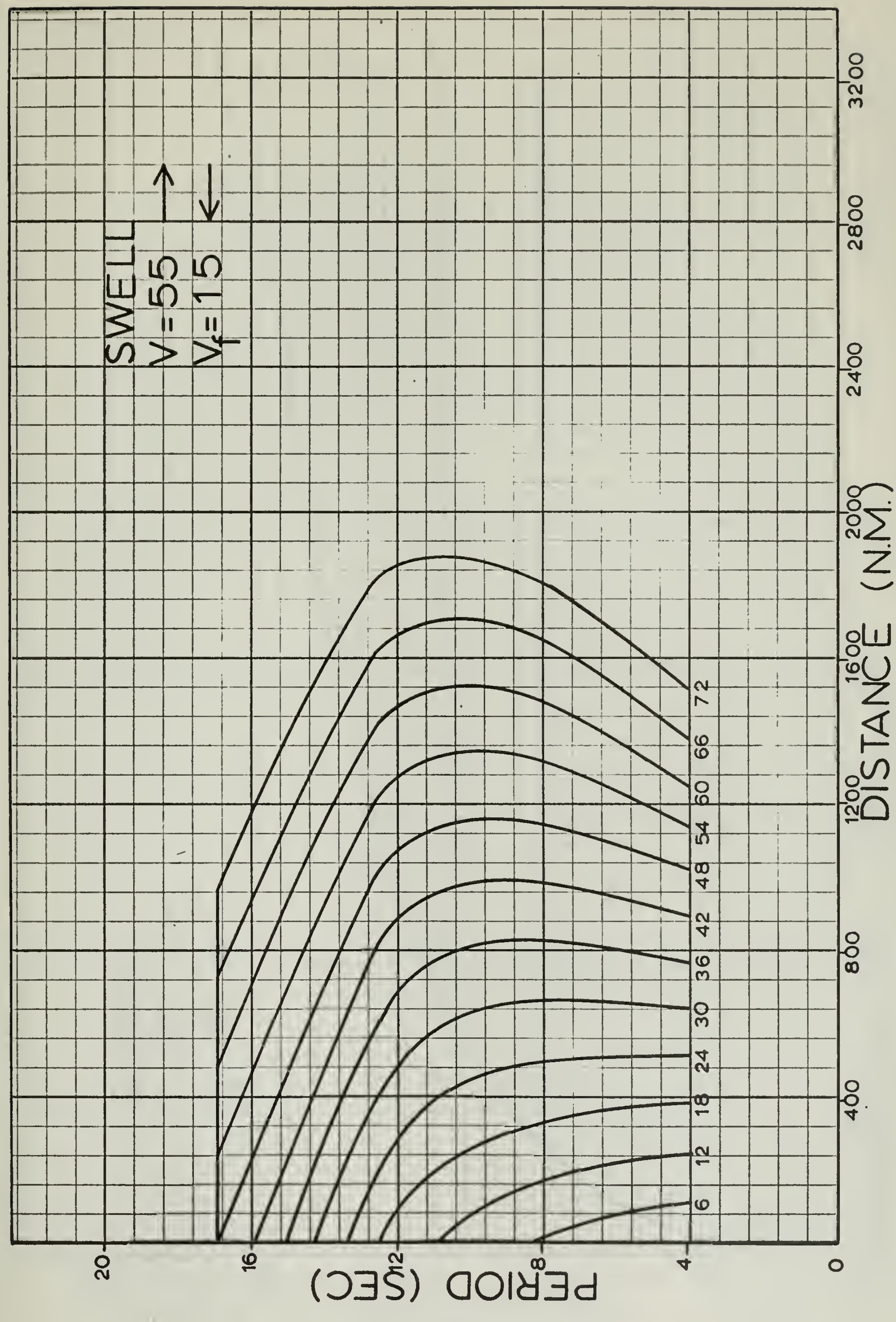


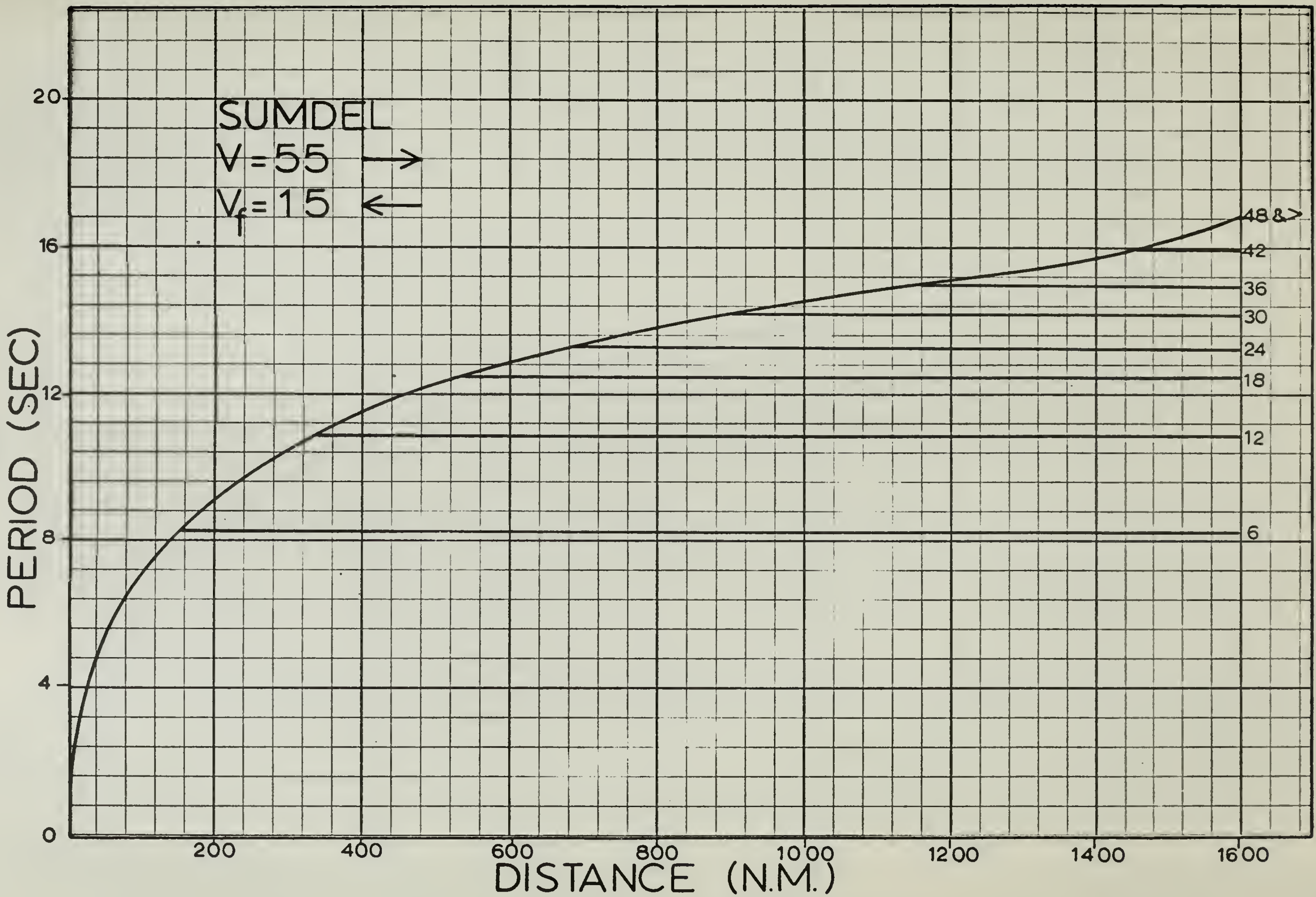
SWELL
V = 50
V_f = 45
DISTANCE (N.M.)
PERIOD (SEC)
0
4
8
12
16
20
500
1000
1500
2000
2500
3000
3500
4000
6
12
18
24
30
36
42
48
54
60
66
72



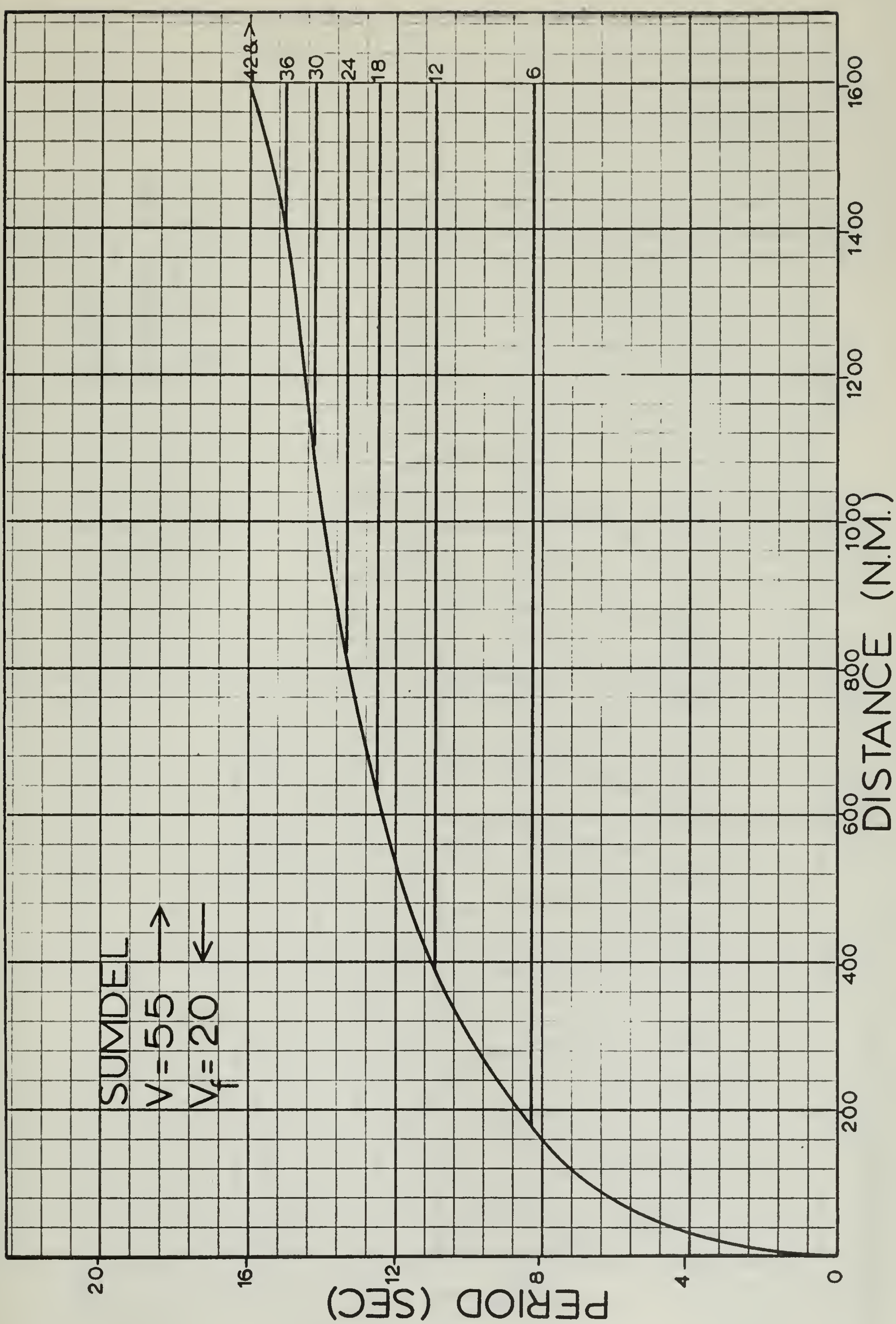
SUMDEL
V = 50 →
Vf = 50 ←
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
24 & >
18
12
6

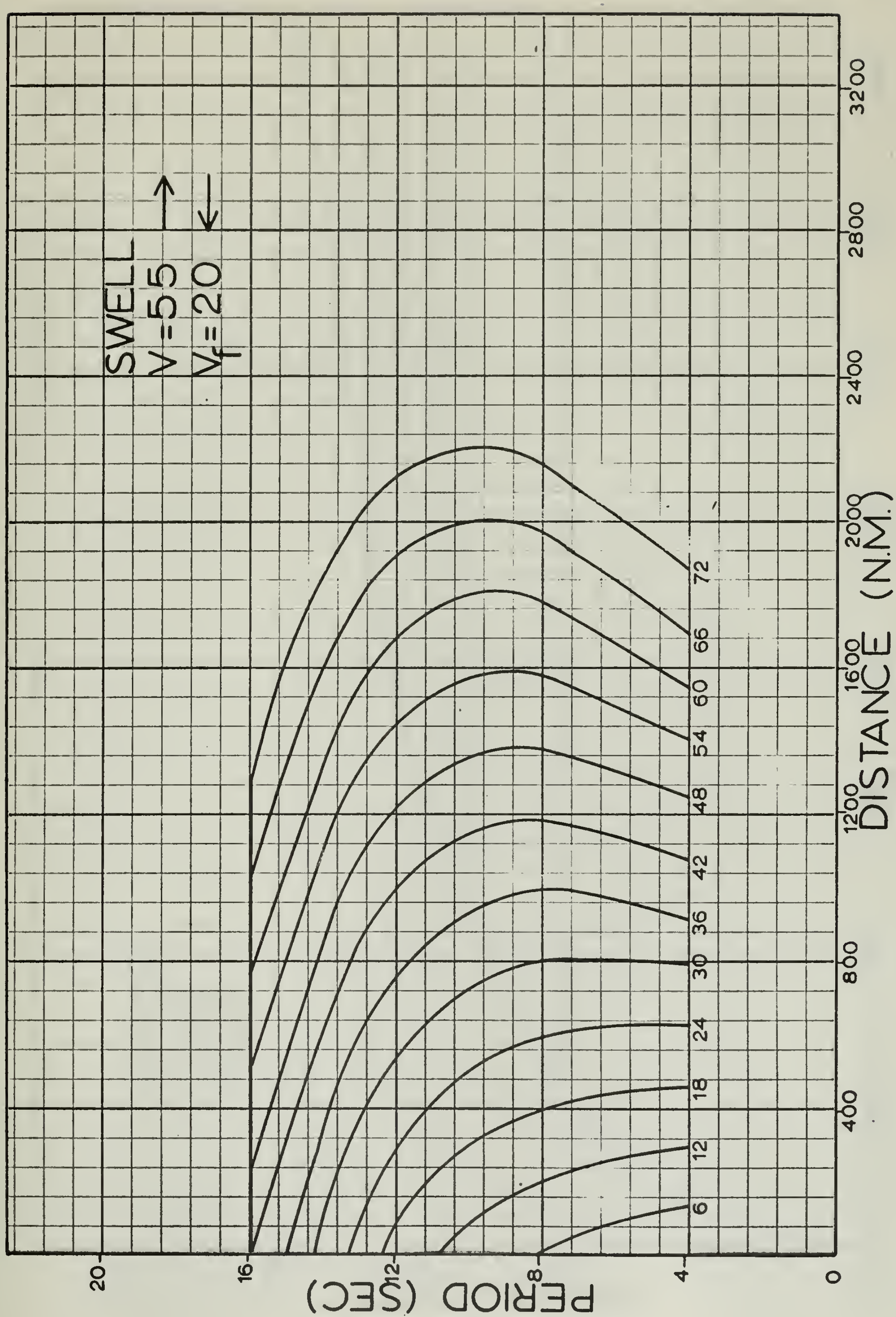

SWELL
V = 50 →
V_f = 50 ←
6
12
18
24
30
36
42
48
54
60
66
72
0
4
8
12
16
20
PERIOD (SEC)
600
1200
1800
2400
3000
3600
4200
4800
DISTANCE (N.M.)


SWELL
V = 55
V_f = 15
DISTANCE (N.M.)
PERIOD (SEC)
0
4
8
12
16
20
400
800
1200
1600
2000
2400
2800
3200
6
12
18
24
30
36
42
48
54
60
66
72



SUMDEL
V = 55
$V_f$ = 15
48 & >
42
36
30
24
18
12
6
PERIOD (SEC)
DISTANCE (N.M.)


SUMDEL
V = 55
V_f = 20
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
6
12
18
24
30
36
42&>



SWELL
V = 55
$V_f$ = 20
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
400
800
1200
1600
2000
2400
2800
3200
6
12
18
24
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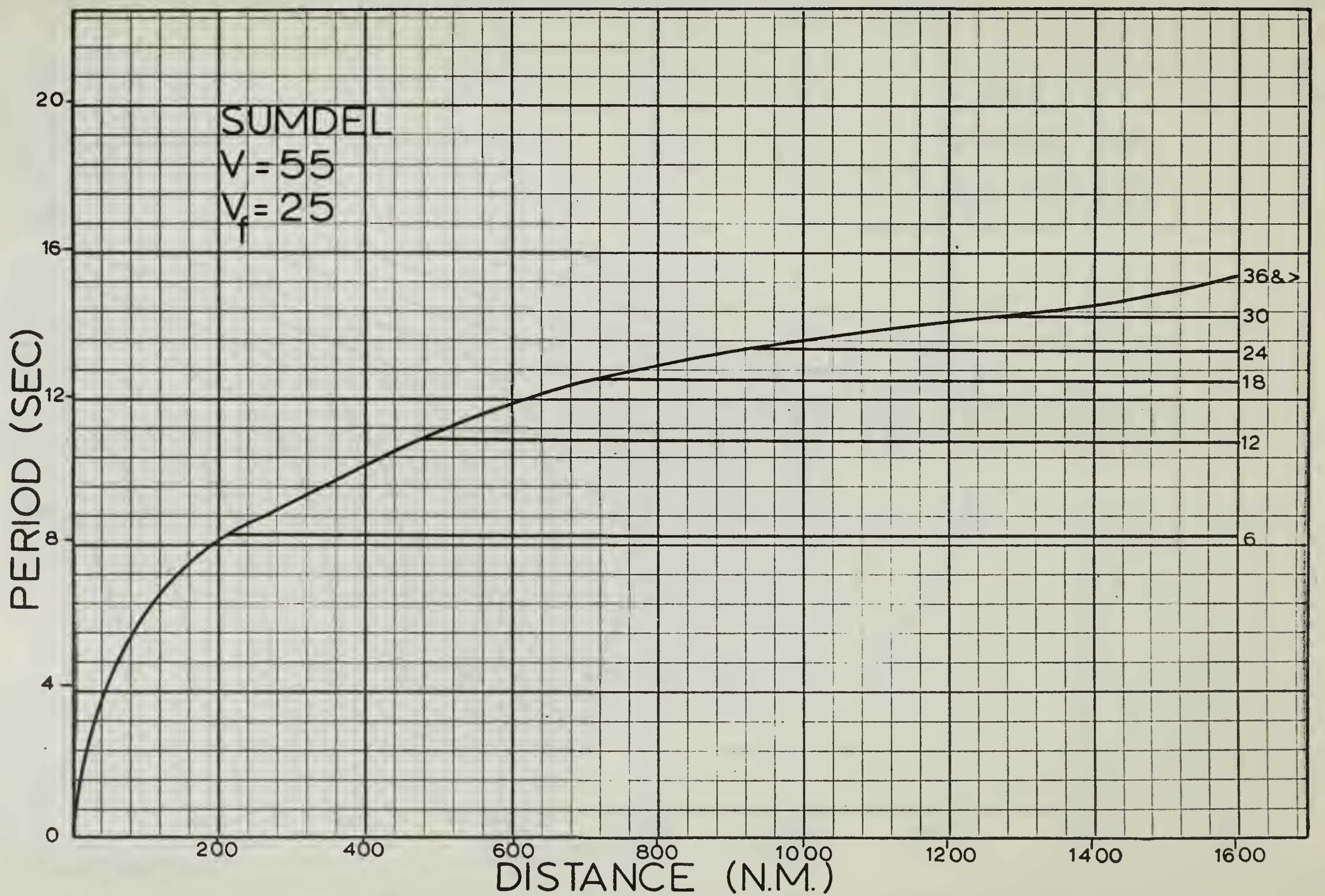
48
54
60
66
72


SUMDEL
V = 55
Vf = 25
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
200
400
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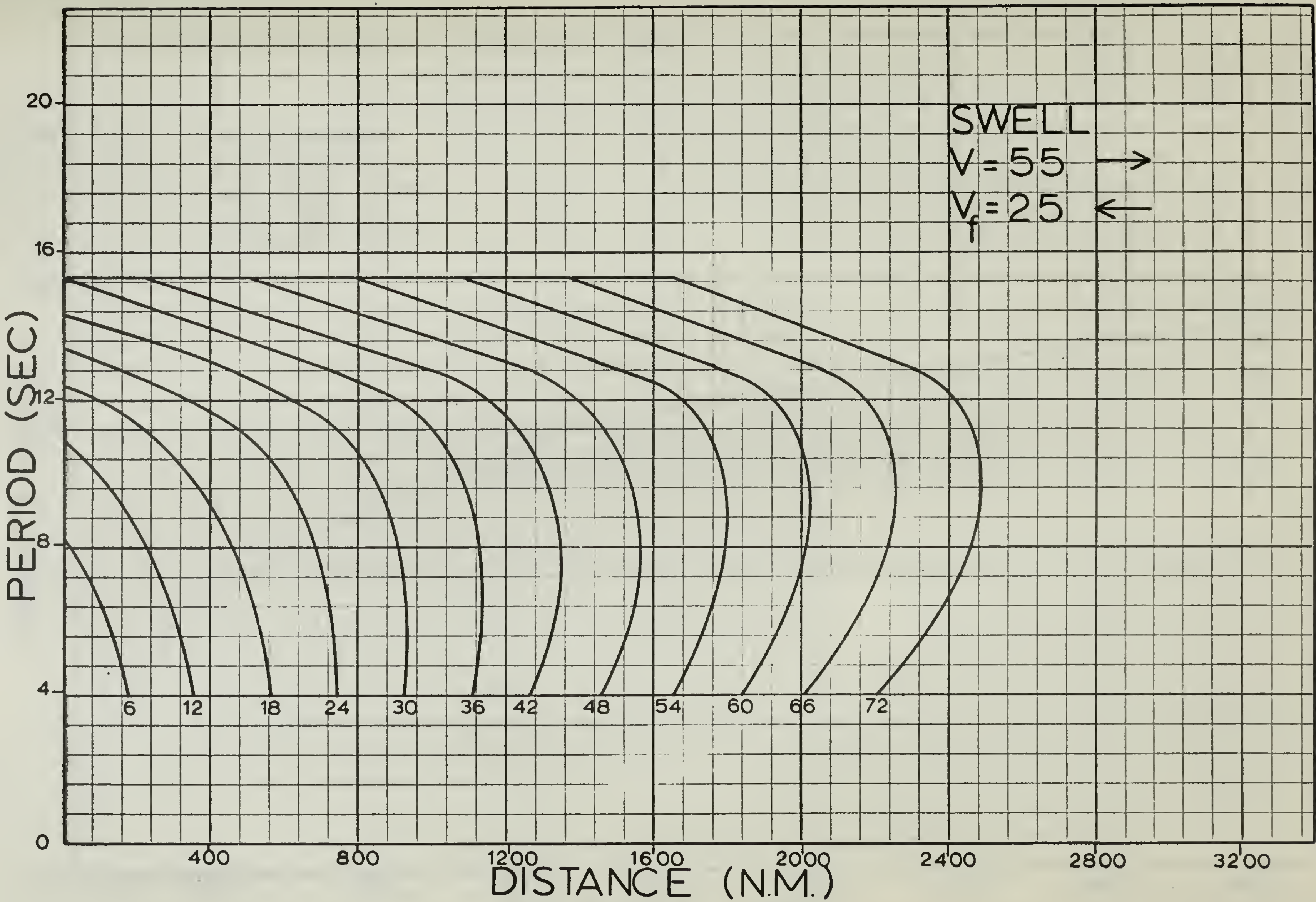
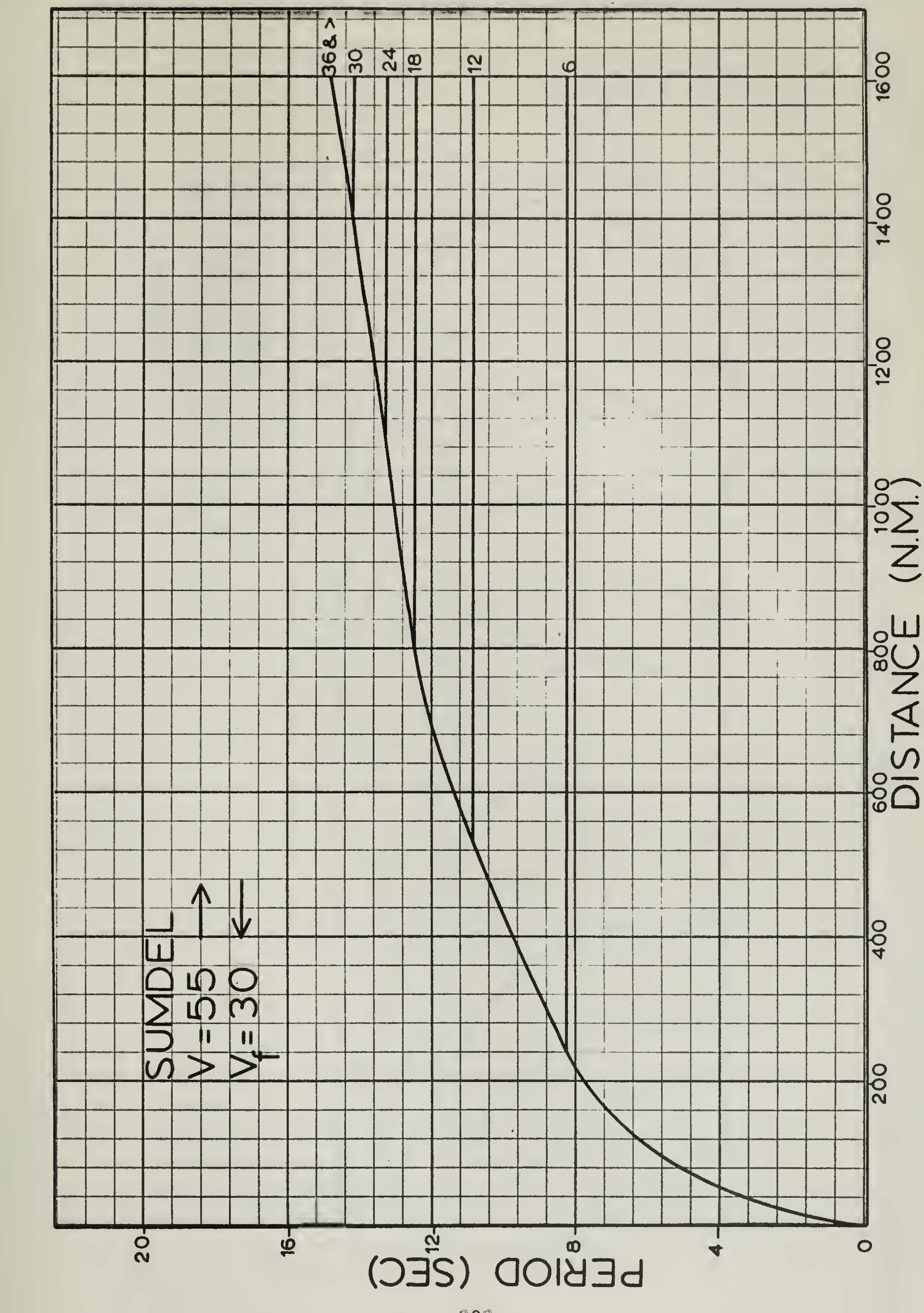
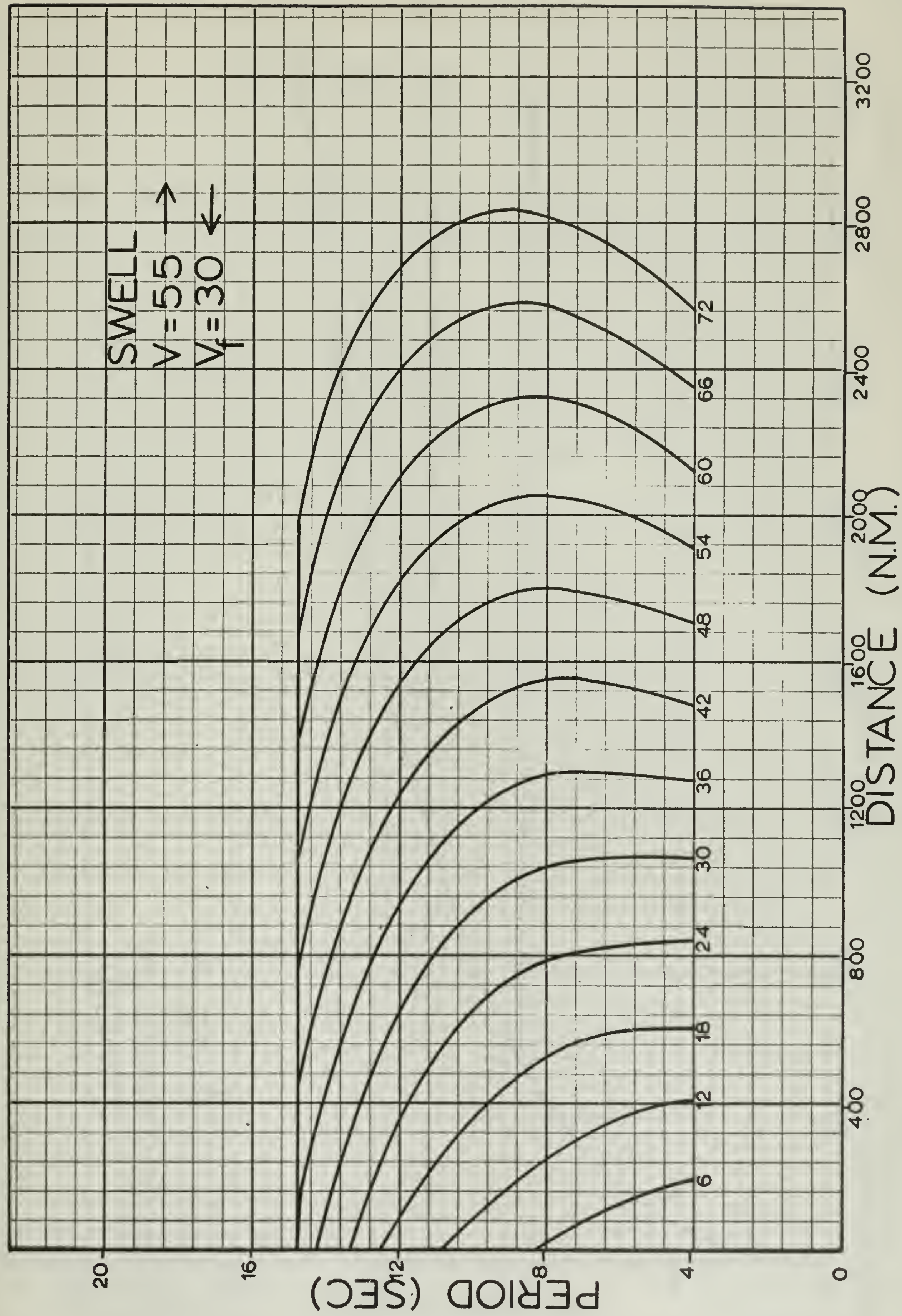
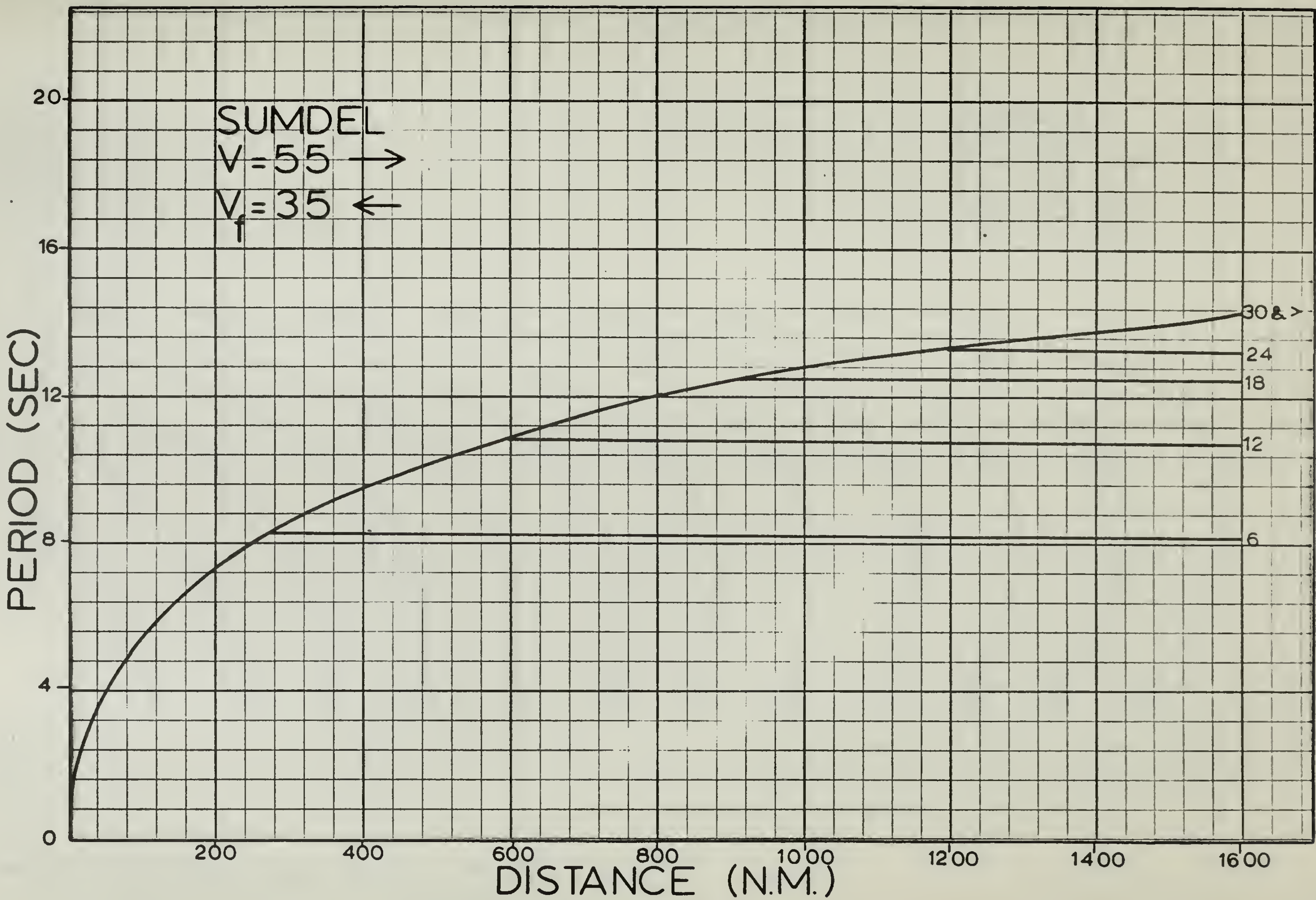
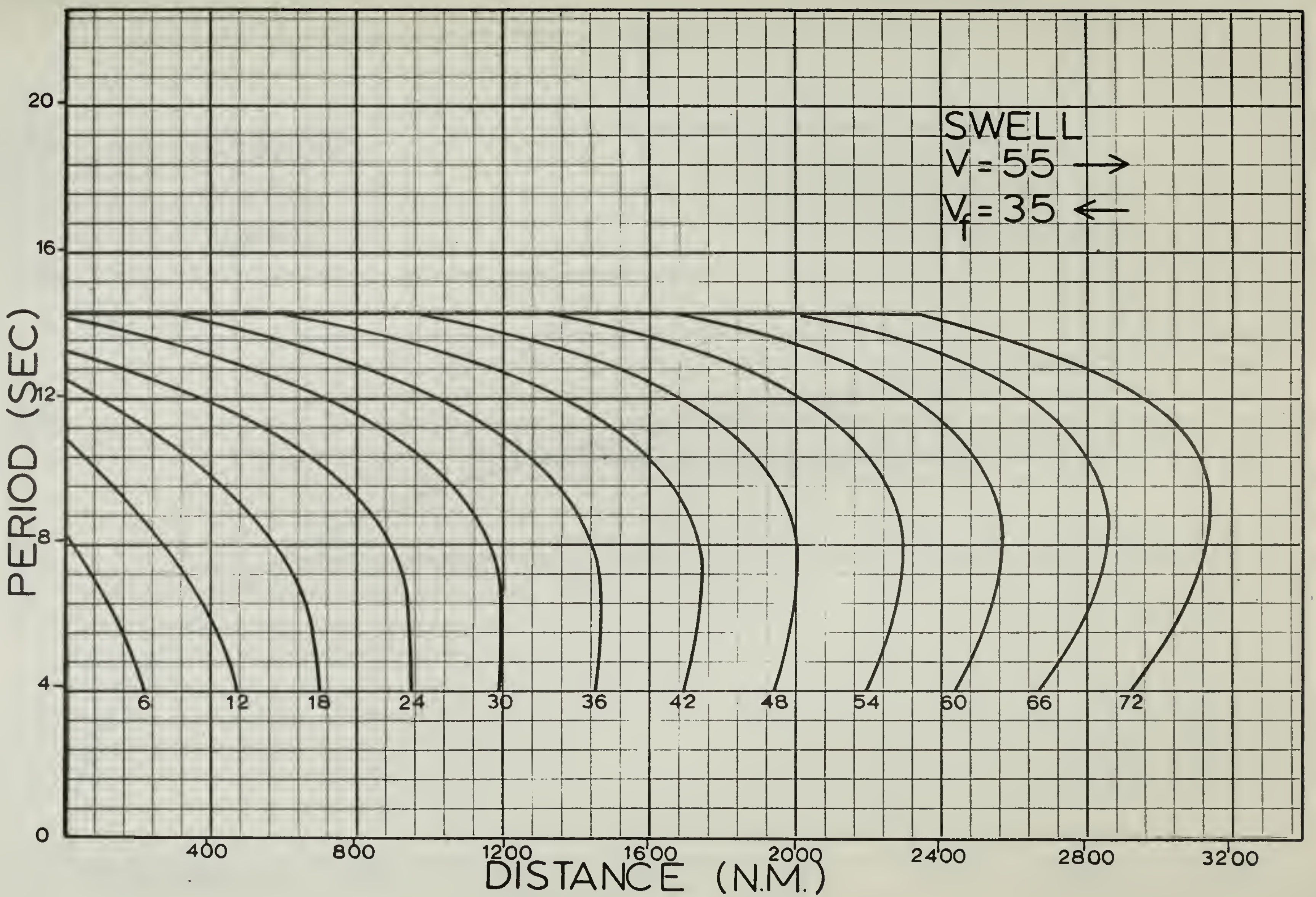
800
1000
1200
1400
1600
36&>
30
24
18
12
6

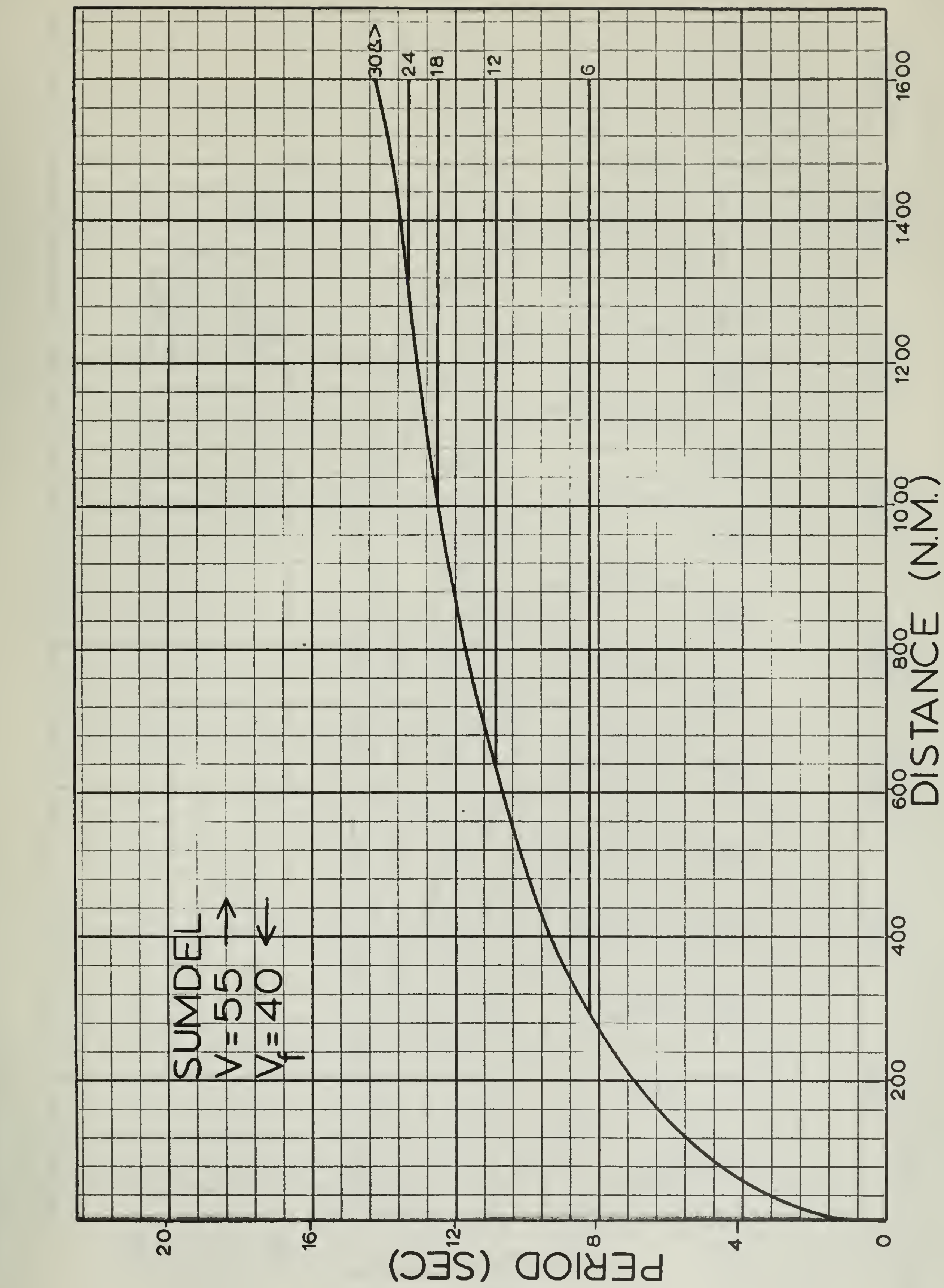

SWELL
V = 55
V_f = 25
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
400
800
1200
1600
2000
2400
2800
3200
6
12
18
24
30
36
42
48
54
60
66
72

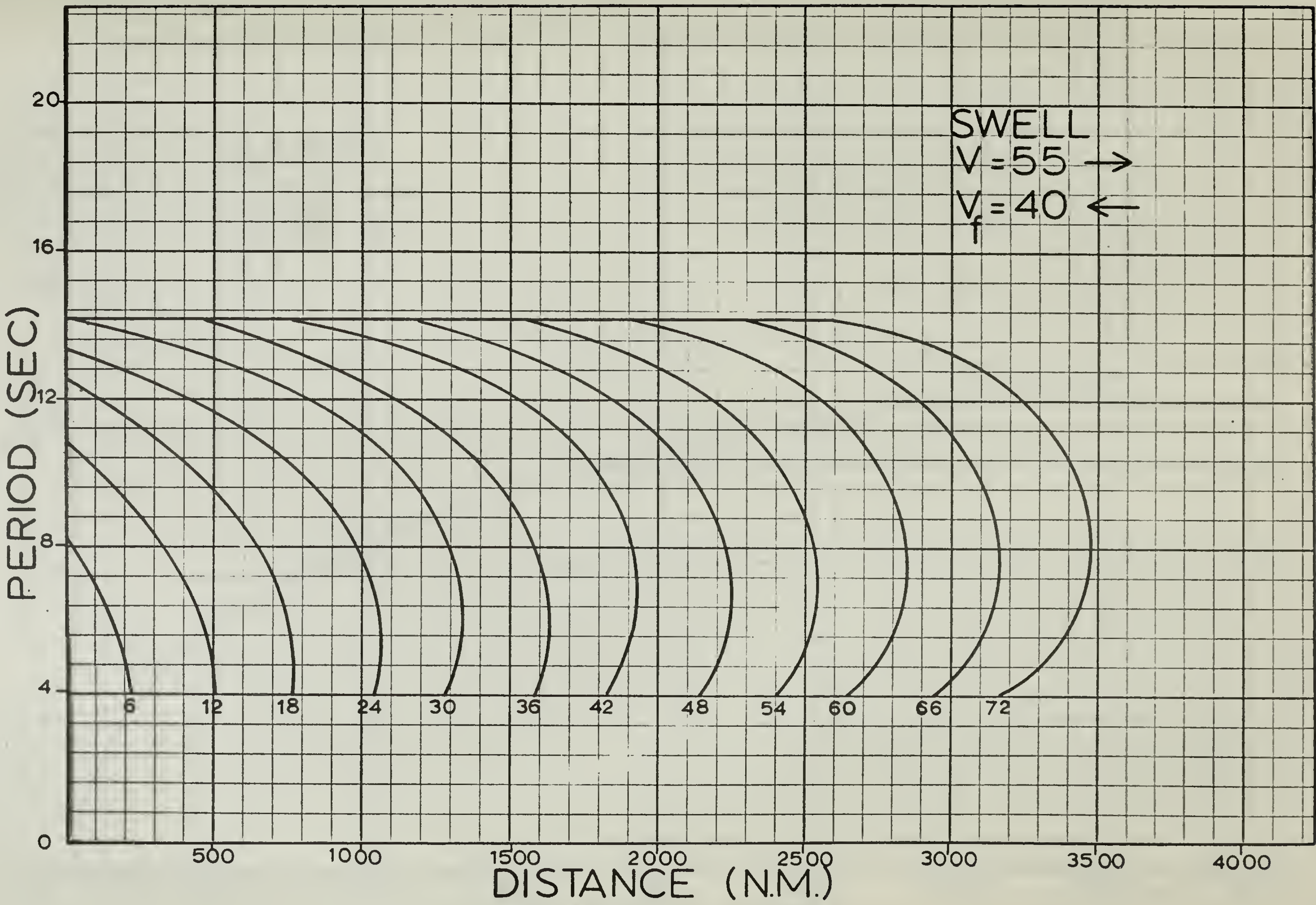

SUMDEL
V = 55
V_f = 30
36 & >
30
24
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600

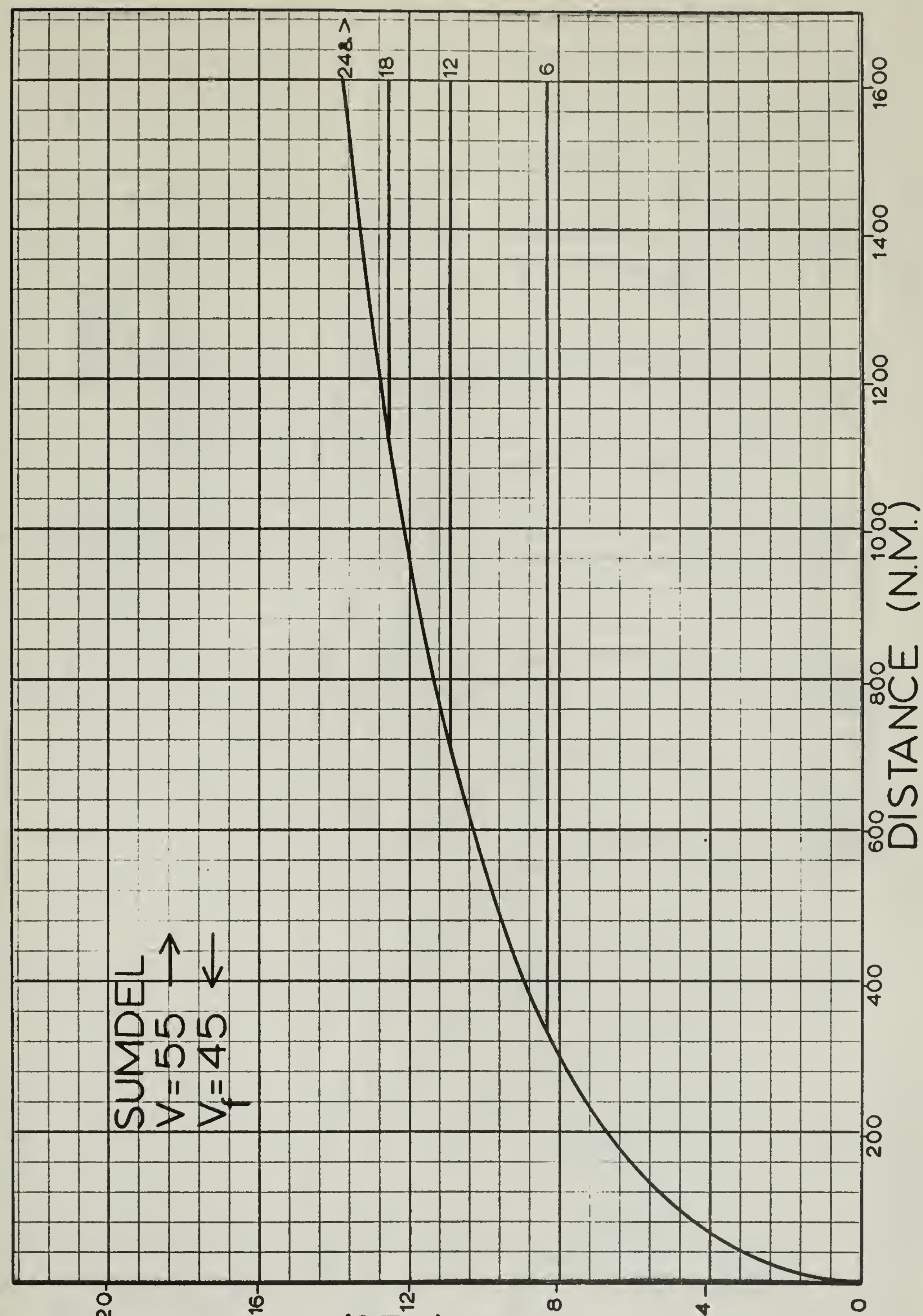

SWELL
V = 55 →
$V_f$ = 30 ←
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
400
800
1200
1600
2000
2400
2800
3200
6
12
18
24
30
36
42
48
54
60
66
72


SUMDEL
V=55 →
V_f=35 ←
30 & >
24
18
12
6
PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600

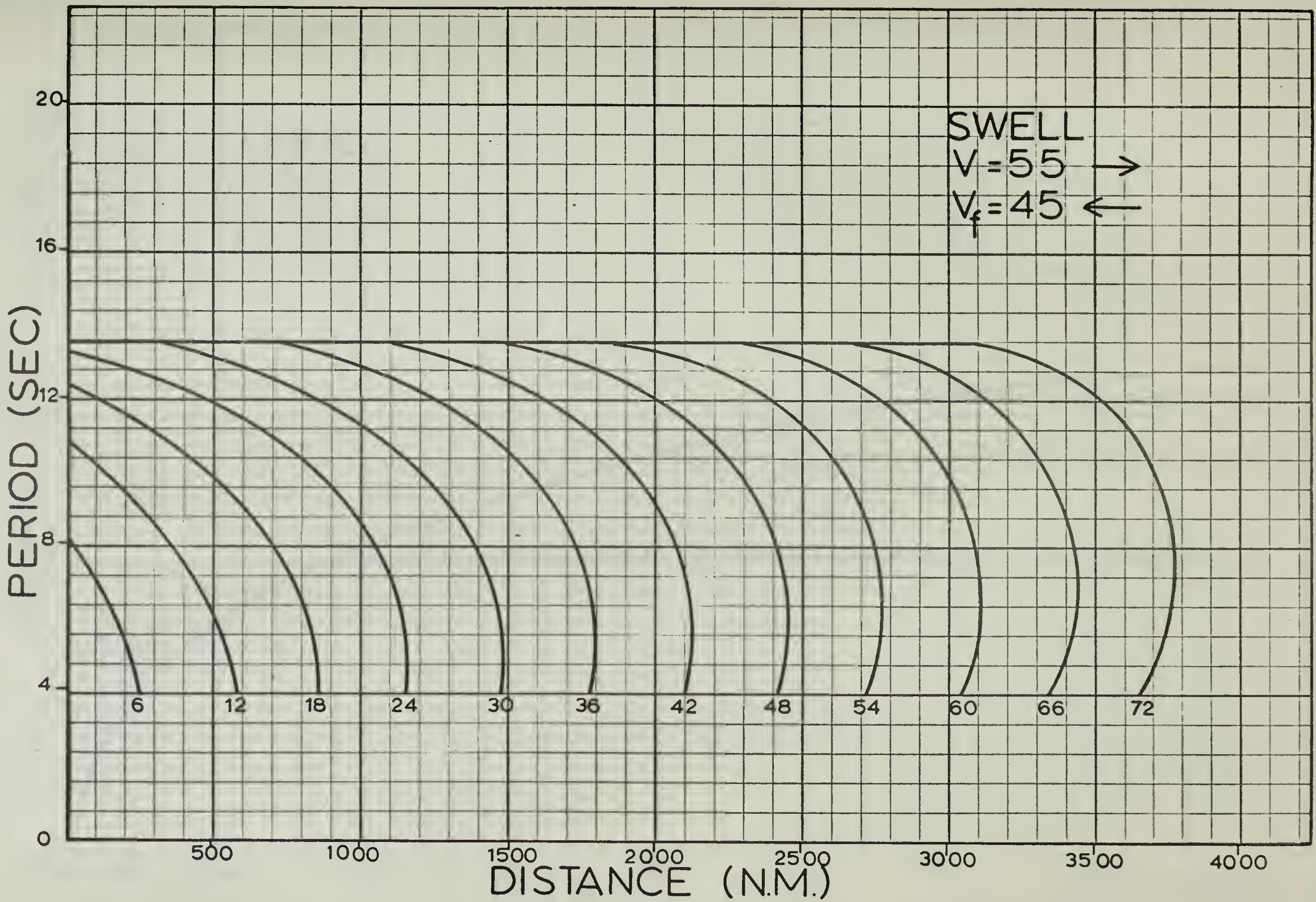

SWELL
V = 55 →
$V_f$ = 35 ←
PERIOD (SEC)
20
16
12
8
4
0
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

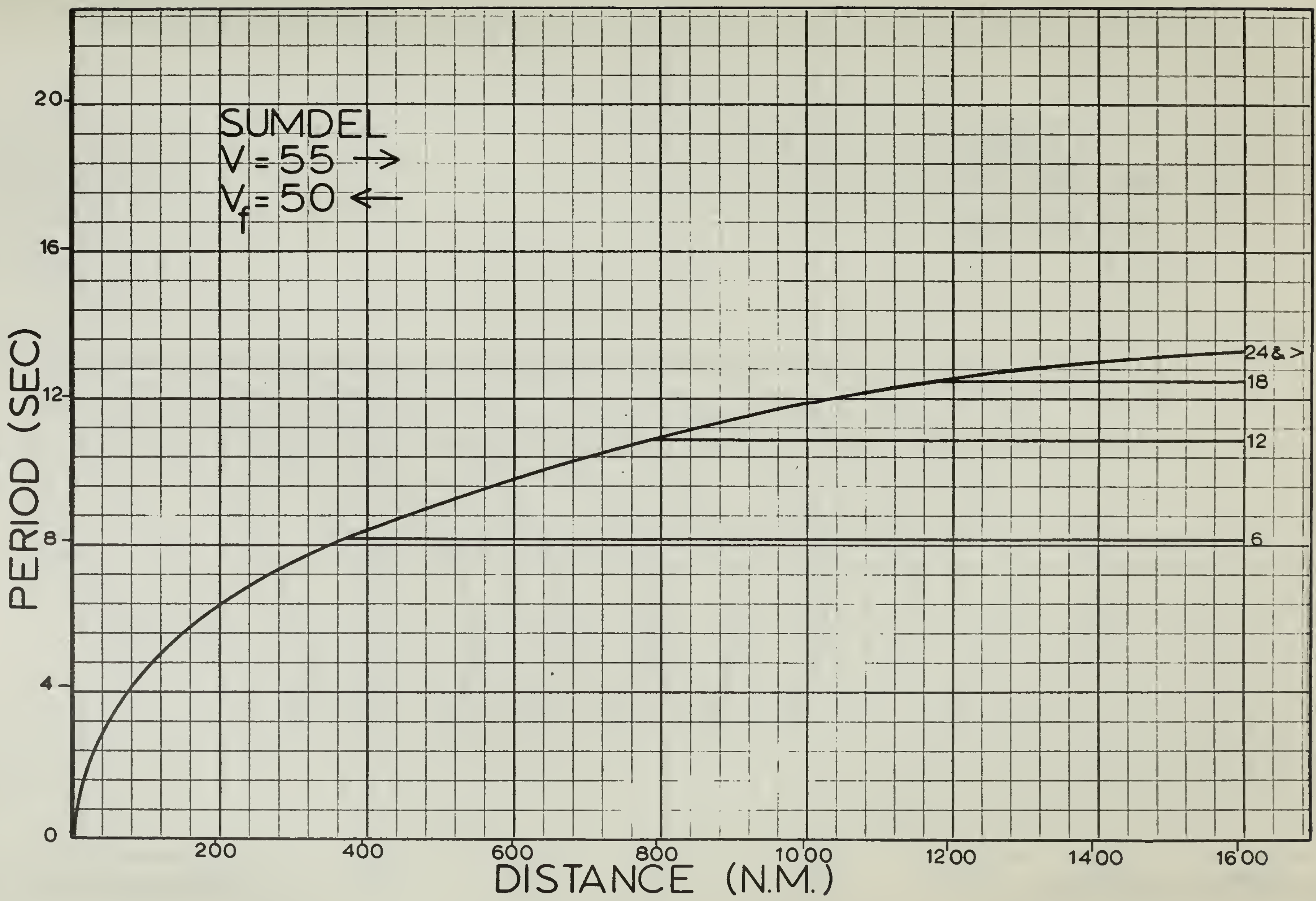

SUMDEL
V = 55 →
V_f = 40 ←
30&>
24
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600

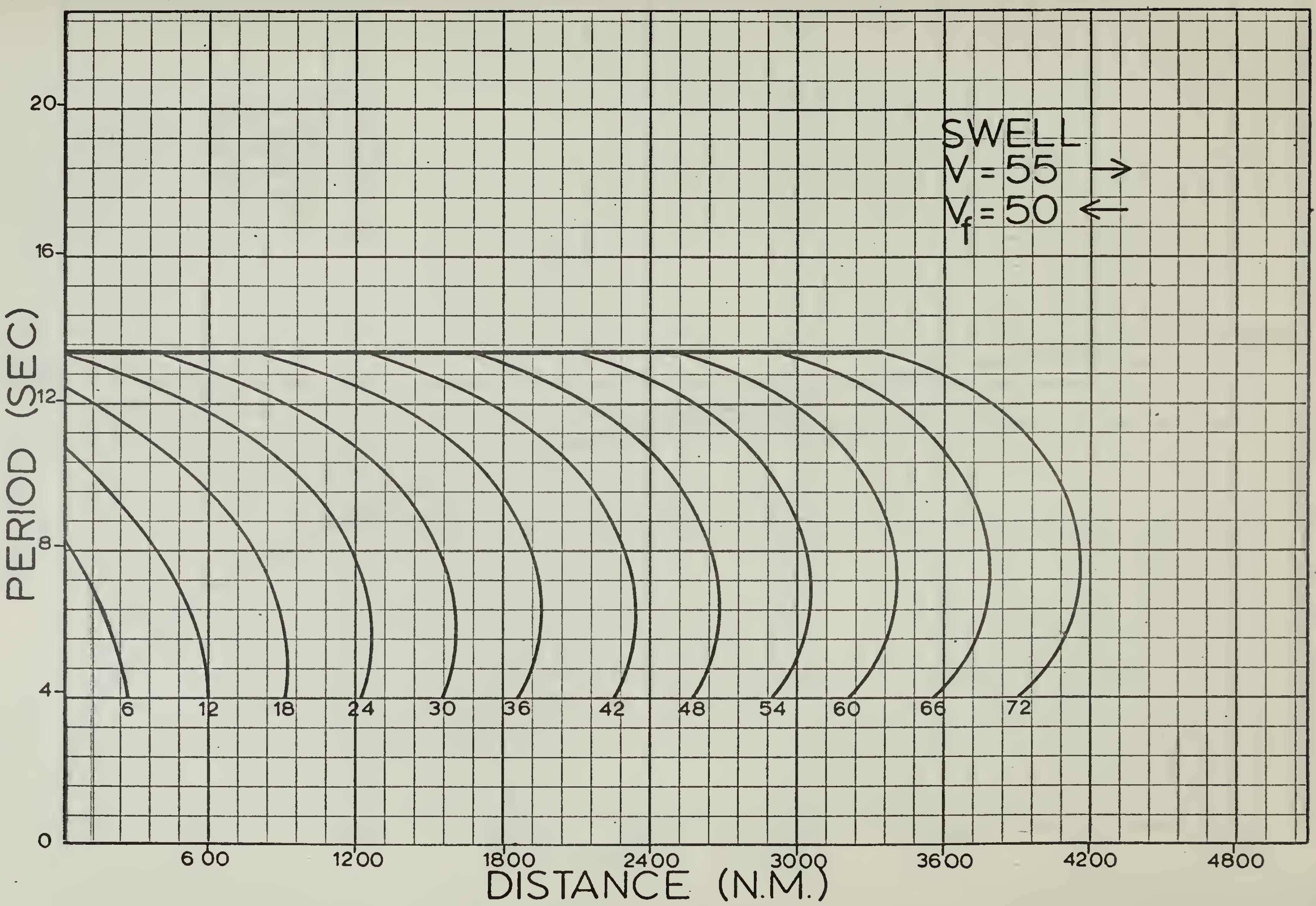

SWELL
V = 55 →
V_f = 40 ←
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
500
1000
1500
2000
2500
3000
3500
4000
6
12
18
24
30
36
42
48
54
60
66
72

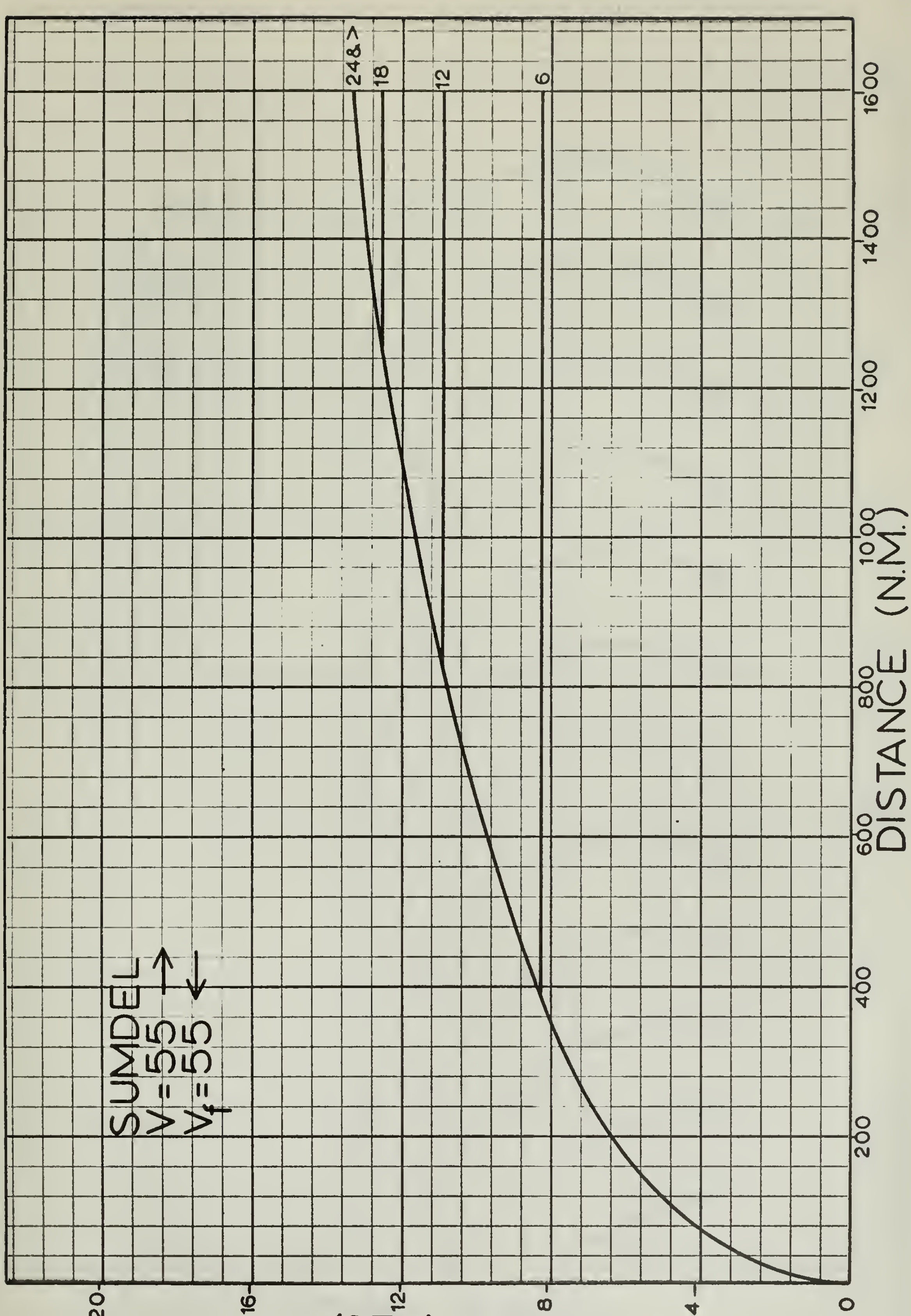


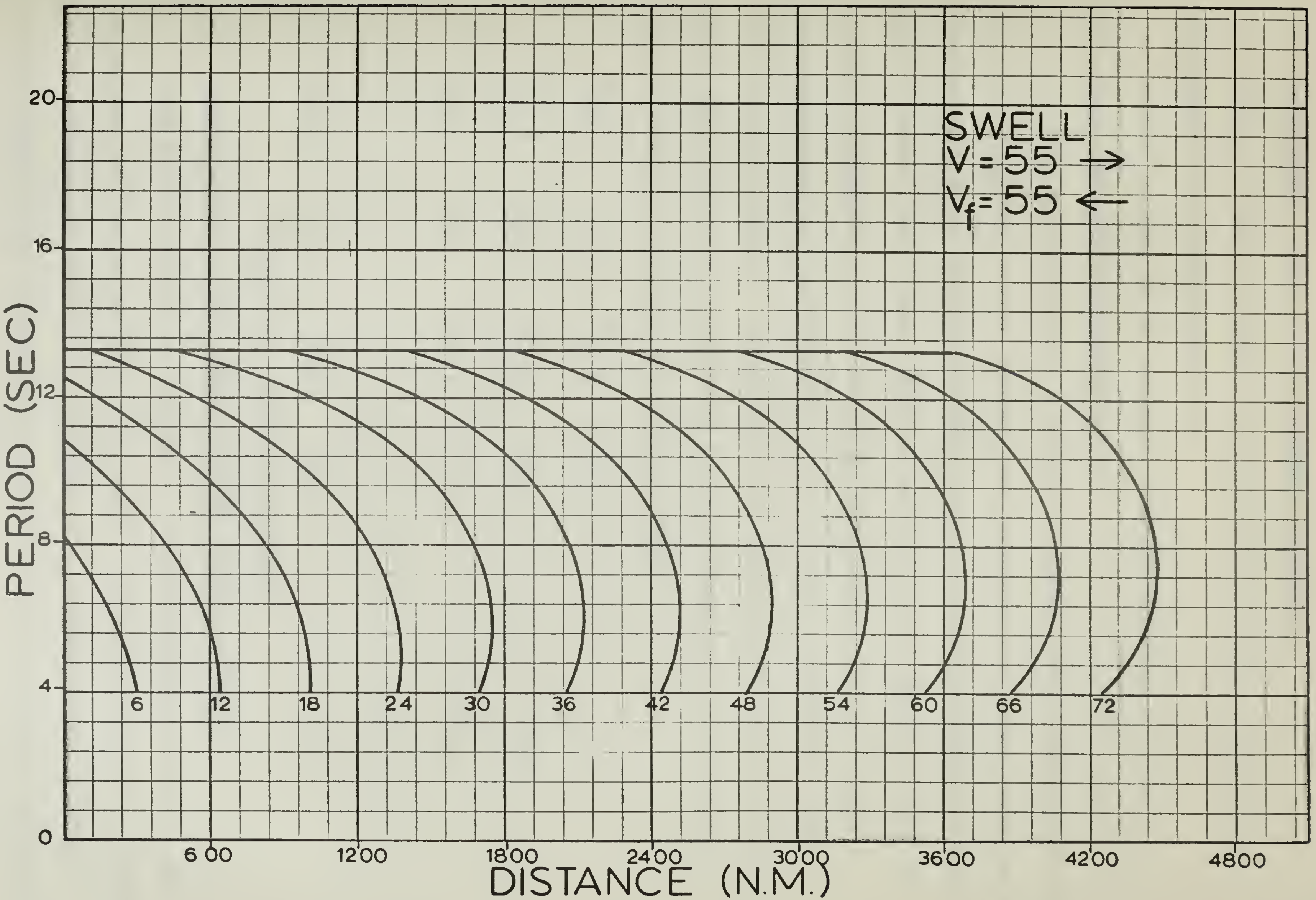
SUMDEL
V = 55 →
$V_f$ = 45 ←
24 & >
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600


SWELL
V = 55 →
$V_f$ = 45 ←
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
500
1000
1500
2000
2500
3000
3500
4000
6
12
18
24
30
36
42
48
54
60
66
72


SUMDEL
V = 55 →
V_f = 50 ←
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
24 & >
18
12
6


SWELL
V = 55
$V_f$ = 50
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
600
1200
1800
2400
3000
3600
4200
4800
6
12
18
24
30
36
42
48
54
60
66
72


SUMDEL
V = 55
$V_f$ = 55
24 & >
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600


SWELL
V = 55
$V_f$ = 55
PERIOD (SEC)
20
16
12
8
4
0
6
12
18
24
30
36
42
48
54
60
66
72
6 00
1200
1800
2400
3000
3600
4200
4800
DISTANCE (N.M.)

## 1. Programming, Computing and Graphing Procedures

Fortran computer language utilizing the Control Data Corporation 1604 computer was used exclusively.

A brief outline of the procedure employed follows.

### 1.1 The Co-Cumulative Spectrum arrays

In order to have a table of values of maximum period and minimum required fetch as functions of wind velocity and generation time, the Co-Cumulative Spectra of Pierson, Neumann and James were read into the program as fifty-five by seventy-two arrays. That is, periods and Fo' were read into the computer memory for each five knots of wind from fifteen to fifty-five knots and every two hours duration time from two to seventy-two hours. Fig. A-1 is a schematic representation of this array for period, $T(V,t_d)$; where (V) is the wind velocity and $t_d$ is the duration. A similar array for Fo' was also read into the computer memory.

$$
\begin{array}{cccccc}
T_{15,2} & T_{15,4} & T_{15,6} & T_{15,8} & \cdots\cdots & T_{15,72} \\
T_{20,2} & T_{20,4} & T_{20,6} & T_{20,8} & \cdots\cdots & T_{20,72} \\
T_{25,2} & T_{25,4} & T_{25,6} & T_{25,8} & \cdots\cdots & T_{25,72} \\
\vdots & \vdots & \vdots & \vdots & & \vdots \\
T_{55,2} & T_{55,4} & T_{55,6} & T_{55,8} & \cdots\cdots & T_{55,72}
\end{array}
$$

Figure A-1. Wave Period Array.

### 1.2 Computations for LAG, SWELL, FOPRIME, SUMDEL or SWEDEL

Each model required the writing of a separate program utilizing the equations outlined in Sections 5, 6, and 7. Since the programs are unique to this thesis and would be of interest only to those readers wishing to pursue further study of these methods, they are not included. They may be

[illegible]

[illegible]

| | | | | |
|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

[illegible]

[illegible]

obtained by contacting the authors through the thesis advisor at the U. S. Naval Postgraduate School, Monterey, California.

1.3 <u>All condition print-out</u>

In order to check the validity of the computations, the programs for each of the three situations were run for the nine values of fetch velocity, fifteen to fifty-five knots, with the wind velocity ranging from the specified fetch velocity up to and including fifty-five knots. When the validity of the computations was verified by random hand analysis, these computed values were then used to set the scaling factor for the proposed graphs of the four variables (LAG, SWELL, FOPRIME and SUMDEL).

1.4 <u>Modification of the Program</u>

Two modifications were necessary in order to use the all-purpose program in the computations required and its adaptation to a graphical output. The first step was the addition of the "call graph" statements. These statements called into the program the subroutine GRAPH.

1.5 <u>The Production Run</u>

For each situation the programs were run for the nine fetch velocities. Each run resulted in a tabulated output (an example of which is enclosed as Fig. A-2) and a graph-output tape. The graph-output tape was then run on the CDC 160 computer in conjunction with the CALCOMP Graph Plotter, utilizing the graph-plot program.

| WIND VEL | FTCH VEL | OB TIME | DURATION | PERIOD | SUMDELD | LAG | LEAD | FOPRIME |
|---|---|---|---|---|---|---|---|---|
| 40 | 15 | 6 | 2 | 4.3 | 16 | 33 | 0 | 0 |
| 40 | 15 | 6 | 4 | 6.0 | 28 | 11 | 0 | 0 |
| 40 | 15 | 6 | 6 | 7.1 | 37 | 0 | 0 | 0 |

| WIND VEL | FTCH VEL | OB TIME | DURATION | PERIOD | SUMDELD | LAG | LEAD | FOPRIME |
|---|---|---|---|---|---|---|---|---|
| 40 | 15 | 12 | 2 | 4.3 | 16 | 84 | 0 | 0 |
| 40 | 15 | 12 | 4 | 6.0 | 28 | 47 | 0 | 0 |
| 40 | 15 | 12 | 6 | 7.1 | 37 | 25 | 0 | 0 |
| 40 | 15 | 12 | 8 | 7.6 | 44 | 13 | 0 | 0 |
| 40 | 15 | 12 | 10 | 8.2 | 49 | 5 | 0 | 0 |
| 40 | 15 | 12 | 12 | 9.1 | 51 | 0 | 0 | 0 |

| WIND VEL | FTCH VEL | OB TIME | DURATION | PERIOD | SUMDELD | LAG | LEAD | FOPRIME |
|---|---|---|---|---|---|---|---|---|
| 40 | 15 | 18 | 2 | 4.3 | 16 | 135 | 0 | 0 |
| 40 | 15 | 18 | 4 | 6.0 | 28 | 82 | 0 | 0 |
| 40 | 15 | 18 | 6 | 7.1 | 37 | 50 | 0 | 0 |
| 40 | 15 | 18 | 8 | 7.6 | 44 | 34 | 0 | 0 |
| 40 | 15 | 18 | 10 | 8.2 | 49 | 20 | 0 | 0 |
| 40 | 15 | 18 | 12 | 9.1 | 51 | 7 | 0 | 0 |
| 40 | 15 | 18 | 14 | 9.6 | 52 | 1 | 0 | 0 |
| 40 | 15 | 18 | 16 | 10.1 | 52 | 0 | 0 | 170 |
| 40 | 15 | 18 | 18 | 10.5 | 50 | 0 | 0 | 230 |

| WIND VEL | FTCH VEL | OB TIME | DURATION | PERIOD | SUMDELD | LAG | LEAD | FOPRIME |
|---|---|---|---|---|---|---|---|---|
| 40 | 15 | 24 | 2 | 4.3 | [illegible] | 186 | 0 | 0 |
| 40 | 15 | 24 | 4 | 6.0 | [illegible] | 118 | 0 | 0 |
| 40 | 15 | 24 | 6 | 7.1 | 37 | 76 | 0 | 0 |
| 40 | 15 | 24 | 8 | 7.6 | 44 | 55 | 0 | 0 |
| 40 | 15 | 24 | 10 | 8.2 | 49 | 36 | 0 | 0 |
| 40 | 15 | 24 | 12 | 9.1 | 51 | 14 | 0 | 0 |
| 40 | 15 | 24 | 14 | 9.6 | 52 | 4 | 0 | 0 |
| 40 | 15 | 24 | 16 | 10.1 | 52 | 0 | 70 | 80 |
| 40 | 15 | 24 | 18 | 10.5 | 50 | 0 | 45 | 140 |
| 40 | 15 | 24 | 20 | 11.1 | 46 | 0 | 20 | 205 |

Figure A-2. Tabulated Computer Output.

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2. New York University, School of Engineering and Science, Research Division. A proposed spectral form for fully developed wind seas based on the similarity theory of S. A. Kitaigorodskii, by Willard J. Pierson, Jr. and Lionel Moskowitz. October, 1963. Department of Meteorology and Oceanography Geophysical Sciences Laboratory Report 63-12.

3. Pierson, W. J. Jr., G. Neumann, R. W. James: Practical Methods for Observing and Forecasting Ocean Waves by means of Wave Spectra and Statistics. H. O. Pub. No. 603; 1955.